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USERS MANUAL:
TSC HIGHWAY NOISE PREDICTION CODE: MOD-04

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Final Report

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In order to maintain consistency between this report and the TSC-MOD 4 computer program, the text of this report utilizes the English system of measurement. For the purposes of this report, the following conversion factors may be used to convert the English units to their International System (SI) equivalents:

To Convert from	To	Multiply By*
feet	metre (m)	0.3048
feet/sec	metre per second (m/s)	0.3048
miles/hr	kilometres per hour (km/h)	1.609
pound (avoir-dupolis)	kilogram (kg)	0.454
degrees Fahrenheit	degrees Celsius	$t_{°C} = (t_{°F} - 32)/1.8$

*Source: "Standard for Metric Practice," E380-76, American Society for Testing and Materials, 1916 Race St. Philadelphia, Pa. 19103

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16. Abstract

The users manual presents a detailed description of the TSC highway noise prediction computer program. The evolution of the TSC program is described to illustrate salient differences between successive versions of the computer code. The version presented in this manual is called the MOD-04 version. The manual relates the analytical basis to the coded statements to indicate how the prediction procedure utilizes input data. The manual describes the features of the MOD-04 version and presents guidelines for formulating problems. Detailed description of input data requirements and example problems are presented to illustrate usage of the computer program. The appendicies to the users manual describe the theoretical basis, computer system details, and subprogram descriptions of the MOD-04 version of the TSC highway noise prediction code.

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ADDENDUM

Technical Notes

This user's manual represents the latest effort in a continuing program to provide an accurate methodology for predicting traffic generated noise levels. It is anticipated that future changes to the computer program will involve incorporation of a 4½ dB(A) attenuation rate to account for ground effects, and the addition of a noise barrier design package.

In making predictions with the MOD-04 program, the user should be aware of two limitations:

(1) The noise emission levels contained within the program are based on cruise conditions and thus are not applicable to situations involving acceleration or grades. In these instances it is recommended that the 55 mph emission levels be used, that is, 82 dBA for medium trucks and 86 dBA for heavy trucks.

(2) The MOD-04 program is capable of make noise predictions for vehicle speeds as low as 20 miles per hour. It is recommended however, that predictions not be made for speeds less than 30 mph. This limitation is recommended since the data base for determining emission levels in the 20-30 mph speed range is not complete.

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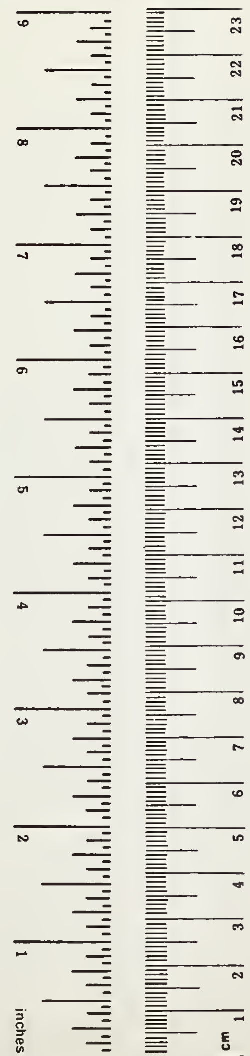
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

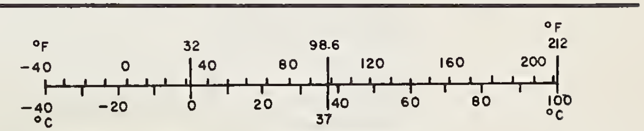
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

This study is one part of the continuing effort to refine and improve engineering methods for the prediction of traffic-generated noise. As a computer prediction technique, the code described in this manual represents another step in the evolution of the highway traffic noise prediction code developed by the Transportation Systems Center (TSC) and originally published in 1972 (1).* Section 2 of this manual briefly describes the evolution of the TSC highway noise prediction code prior to initiation of the present effort.

As a user's manual, this report attempts to satisfy two needs. First, a description of the traffic noise prediction scheme that focuses only on the consideration of problem formulation and predicted results is presented in Sections 3 through 7 of the manual. This description should be sufficient for highway planners and engineers who do not require a detailed knowledge of the code. Second, the appendices to this manual present a detailed discussion of both the mathematical models used and the coded translation of these models. Hence, the appendices to this manual provide a detailed description of the code mainly of interest to computer systems personnel and data processing organizations. There remains the gray area between these two requirements in which the engineer needs detailed knowledge of the code and the computer systems analyst needs detailed knowledge of the physical problems that apply to the model. One can only rely upon study and experience if job requirements force one to move from engineering application to computer systems analysis. Such considerations are discussed in Section 3.1 and Section 5.

As a user's manual, attention has been focused upon describing the salient features of the code that directly relate to problem

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* Numbers in ( ) denote references at the end of the report.

formulation and interpretation of the predicted results. If one has utilized previous versions of the TSC Highway Noise Prediction Code, very little difference in input data requirements or the output data format will be noted. However, the modifications incorporated in this code will, hopefully, yield more accurate sound level predictions. These modifications are briefly described in Section 2.2 and are detailed in the Appendices. The authors hope that the manual does what it is supposed to do (i.e., be useful).

2. BACKGROUND

This Section briefly describes the evolution of the TSC Highway Noise Prediction Code to the configuration described in this manual. The modifications of the previous versions of the code that have been implemented to attain the present configuration are also discussed. Finally, a discussion of the mathematical models utilized to formulate the code is presented in relation to the real-world situation that is being modeled.

2.1 EVOLUTION OF THE TSC/FHWA HIGHWAY NOISE PREDICTION CODE

The present version of the TSC Highway Noise Prediction Code is one more step in an evolutionary process begun in the early 1970s.

The basic problem that has been formulated is a prediction scheme for noise generated by freely flowing*highway traffic. The prediction scheme utilizes a computer code to relieve the engineer of possibly several thousand menial calculations and decisions. The basic code was developed by Bolt, Beranek and Newman, Inc., under contract to the United States Department of Transportation and published in 1972 (3). Although the reports carry an earlier publication date than that of the BBN study (3), the Transportation Systems Center published both a computerized prediction method (1), and a short manual method (2) for estimating highway traffic noise. The TSC computer code described in Reference (1) is undoubtedly an evolution of the BBN code (3) and differed from the BBN code essentially in the manner in which statistical parameters were calculated in order to estimate the percentile sound levels L_{90}, L_{50}, and L_{10} for freely flowing traffic. At this stage of evolution, the code became known popularly as the "TSC Method" of traffic noise prediction.

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* The traffic flow model used to predict noise levels assumes a constant speed and constant headway distribution for each vehicle type.

Between 1972 and late 1974, users of the TSC code had established two salient characteristics when applying the code to real-world problems. First, the predicted sound levels seemed to be too high when compared to measured data and other prediction schemes (4). Also, it appeared that certain geometrical configurations and/or alignments between the highway source, intervening barriers, etc., and the receiver caused either faulty output or fatal execution of the program. These characteristics have caused some concern to users of this code.

To remedy the problems associated with the geometrical description of the traffic noise prediction code, the Transportation System Center issued a revised version of the code in October 1974 (5). This revised version of the TSC highway noise prediction code can be recognized from previous versions by the presence of the subprograms COLIN, IAREA, DEGEN, and MOVE2. These modifications, however, were not fully documented in Reference (5) due to the urgency of distributing the modified version to users. The modifications implemented in this version of the TSC Prediction Method did not affect the sound-level estimates, however.

About mid-1976, the Federal Highway Administration, in conjunction with the highway agencies of the states of Colorado, Florida, North Carolina, and Washington, and the Transportation Research Center had completed a field measurement and data reduction program to establish the speed dependence of vehicle noise emissions for trucks.

This program provided sound level data in the speed range of 20 mph to 70 mph for totals of 554 medium-truck (two axle, six tires) pass-by events and 1,654 heavy-truck (three or more axles) pass-by events (6). By conducting a nonlinear regression analysis of these data, both sound level and standard deviation of sound levels were expressed as quadratic polynomials of vehicle speed for medium- and heavy-duty trucks. Hence, the data base existed for revision of the reference sound levels defined by the 1974 TSC

Noise Prediction Code (5). Additionally, comments were received by the Federal Highway Administration (7) that indicated that additional documentation, clarification, and revision of the TSC Code might be warranted. At this point in time, the study resulting in this manual was formulated.

2.2 BRIEF DESCRIPTION OF MODIFICATIONS IMPLEMENTED

The computer code described in this manual is a documentation and revision of the 1974 version of the TSC Highway Noise Prediction Code (5). The documentation provided for this version of the code is presented in detail in the following sections of the manual and in the Appendices. In particular, a detailed description of the code is presented in Appendices B through E.

The revisions implemented to update the 1974 version to the present configuration basically involved minor changes in the computational sequence, a "clean up" of certain operations that undoubtedly are a result of evolution, modification of the vehicle reference levels, and certain details of the sound propagation model. The line-for-line description of these modifications is presented in the final report for this study (8).

The most significant modification implemented is the inclusion of a medium truck vehicle type and the consideration of the variation of vehicle noise emission characteristics with vehicle speed. The present version of the TSC Noise Prediction Code now considers four vehicle types: automobiles, and light trucks, Type 1; heavy trucks (3 or more axles), Type 2; medium trucks (2 axles), Type 3; and a user-defined Type 4 vehicle.

Based upon field experience (9), the upper limit on barrier attenuation has been reduced from 24 dB to 20 dB, and the upper limit on absorption resulting from shrubbery or trees has been reduced from 30 dB total to 20 dB total.

The section of code in subroutine GEOMRY that utilizes vehicle source height effects (for automobiles only) in determining an appropriate subsegment of roadway for estimating receiver sound levels during diffraction has also been modified to ensure proper utilization of data internal to the subroutine.

Although not explicitly a modification, the documentation now provided for the code is more thorough than was previously available to users. Hopefully, the documentation will allow the code to be more easily understood and, if required, the user can certainly expand the size of the problems considered by modifying the array sizes (see Appendices B, C, D, and E).

2.3 ORGANIZATION OF MANUAL

All versions of the TSC Highway Noise Prediction Code utilize a mathematical model for noise emissions from freely flowing traffic and a mathematical model of the geometry defining the source-path-receiver locations. These models are approximations of the real-world situations encountered by highway planners and engineers. Since approximations are utilized, the traffic noise prediction code can be most effectively utilized if one understands the basis of problem formulation within the limitations of the models utilized.

As a computerized prediction model, certain limitations as to the size of problem to be solved are required. This version of the traffic noise prediction code is limited to sizes of problems that are considered to be beyond that amenable to hand calculation but not so large that difficulties in implementation on a computer system are expected. As discussed in Section 3, the problem size is defined in terms of eleven basic parameters. Using the presentation given in Appendix B, the problem size can be rather easily expanded as might be required.

Section 3 presents a user-oriented discussion of the highway noise prediction code. The discussion is centered on the definition of the traffic noise source and the definition of real-world geometry utilizing the models defined by the code.

Section 4 describes, briefly, the specific features of the traffic noise prediction code that may be utilized in simulating practical highway configurations. A detailed discussion of the theoretical basis of the models is presented in Appendix A and a detailed discussion of the subprograms utilized by the code is presented in Appendix E.

Section 5 presents notes and commentary on formulating problems using the traffic noise prediction code. The user should read this section carefully since it reflects the utilization of the code based upon its inherent characteristics. Explicit reference to subprograms and/or blocks of code are presented to emphasize the detailed knowledge required to thoroughly understand the calculation procedure and, hence, the predicted results.

Section 6 presents a discussion of the input data requirements to utilize the traffic noise prediction code.

Section 7 presents example problems selected to illustrate both input data requirements and output data format.

Section 7.4 presents a brief before-and-after comparison of traffic sound level predictions using the 1974 TSC version and the present version of the code.

3. PREDICTION MODEL OF HIGHWAY TRAFFIC NOISE

3.1 OVERVIEW OF PROBLEM DEFINITION

The prediction of highway traffic noise requires the definition of both the traffic noise source and the noise propagation path from the source to the receiver. The computerized highway traffic noise prediction code described in this manual basically combines speed-dependent reference sound levels (by vehicle types) with a defined source-receiver geometry to estimate sound levels at receiver locations. Hence, the user is required to define the traffic flow conditions and highway alignments to describe the traffic noise source and to define the noise propagation path from the highway to each receiver by describing the geometry and acoustic characteristics of the site between the source and the receiver.

This section of the users manual describes the definition of the traffic noise source and the noise propagation path in terms of the parameters utilized by the prediction code. The detail description of the acoustic models utilized and the structure of the prediction code is presented in the appendicies.

3.1.1 Basic Parameters Defining A Problem

The description of a problem utilizing the highway traffic noise prodiction code presented in this manual requires a specification of eleven (11) basic parameters. These parameters are related either to the source description, the path description, or the sound levels predictions at receiver locations as follows:

Source Parameters (See Section 3.2):

- The number of roadways, NR, defined by both the highway alignment and the traffic flow conditions. The present version of the prediction code is limited to 20 roadways.
- The number of straight line segments, NRSM1(NR), defining the alignment of each roadway. The present version of the prediction code is limited to ten (10) straight line segments for each roadway.

- The number of vehicle types, NQ, that are used to define partially the traffic flow conditions on a roadway. The present version of the prediction code defines three vehicle types that may be specified as well as an optional, user-specified vehicle type. Hence , in the present version of the code, a maximum of four (4) vehicle types is allowed.
- The number of traffic flow conditions, NQS(NR,NQ), defined for each roadway. The present version of the prediction code is limited to five (5) traffic flow conditions for each roadway. A traffic flow condition is defined by a combination of speed and traffic capacity for each vehicle type present on the roadway.
- The number of octave band center frequencies, NF, at which traffic sound level predictions are desired. If NF is specified as equal to 1, only the overall A-weighted sound level is calculated. If NF is specified as an integer between 2 and 9, the prediction code calculates, independently, the A-weighted octave band sound levels beginning at 63 Hz up to the specified limit as follows:

NF	2	3	4	5	6	7	8	9
f_c,Hz	63	125	250	500	1000	2000	4000	8000

  See Appendix A, Section A.3, for a detail discussion of spectral calculations conducted by the code. The user should not associate prediction accuracy with the specification of NF since the prediction code conducts independent calculations for the overall A-weighted sound level and for each octave band center frequency at each receiver.

Path Parameters (See Section 3.3):

- The number of barriers, NB, used to define barriers, berms, rolling topography, buildings, etc, describing the site. The prediction code considers either a perfectly reflecting

barrier (zero absorption coefficient) on a perfectly absorbing barrier (unit absorption coefficient). The present version of the prediction code allows a maximum 20 barriers to be specified.

- The number of straight line segments, NBSM1(NB), defining the top edge of a barrier. The present version of the prediction code is limited to ten (10) segments for each barrier.
- The number of absorptive ground strips, NG defining rectangular patches of ground cover. The present version of the prediction code defines two types of ground cover, and is limited to a total of ten (10) absorptive ground strips.
- The type of absorptive ground strip, IDUM(NG), specified as either low ground cover (IDUM = 1) associated with shrubbery or high ground cover (IDUM = 2) associated with foliated trees. (See Appendix A, Section A.7)

Receiver and Sound Level Parameters (See Section 3.4);

- The number of receiver locations, NRC, at which the traffic noise predictions are desired. The present version of the traffic noise prediction code is limited to a maximum of 15 receiver locations.
- The number of reflections encountered at each receiver, IDXR, is limited to a maximum of 10 for each receiver by the present version of the prediction code.

The above parameters are those specifying the size of the problem being considered by the user as well as the maximum permitted size allowed by the present version of the prediction code. The specific parameters required to conduct traffic noise predictions are described in detail in Section 6.

3.1.2 Basic Problem Considered By The Code

The traffic noise prediction code described in this manual solves one basic problem: the estimation of the acoustic intensity at a receiver location resulting from a straight line roadway segment (source). This basic problem is considered for each roadway segment and receiver combination. Independent calculations are conducted by the code for the overall A-weighted sound level and the A-weighted octave band sound pressure levels.

During the calculation procedure for each roadway segment/receiver configuration, the code considers the effect on acoustic intensity of roadway segment/receiver distance and intervening barriers, topography, shrubbery, trees, and atmospheric absorption. The basic geometry, which is three-dimensional, associated with a roadway-segment/receiver configuration is illustrated in Appendix A, Figure A-1.

In calculating the acoustic intensity at a receiver location from a roadway segment, the prediction code subdivides the roadway segment. The basic criterion, applied at the receiver location, requires that the acoustic intensity radiated by a roadway subsegment be uniform. If neither a diffraction nor an absorptive ground strip is encountered within the triangle formed by the roadway segment end points and the receiver, no subdivision of the roadway segment occurs. If an absorptive ground strip or a segment of an absorptive ground strip is encountered with this roadway segment/receiver triangle, the roadway segment is subdivided into subsegments representing unattenuated and attenuated subsegments. If a diffraction is encountered, the roadway segment is subdivided into subsegments representing portions of the roadway segment that are affected by either diffraction by a barrier, an absorptive ground strip, or are unattenuated. The roadway subsegment affected by barrier diffraction is further subdivided so that the basic assumption of uniform reception of acoustic intensity at the receiver is satisfied. (See Appendix A, Section A.6, Equation (A-21).) Hence, the prediction code appropriately subdivides a user defined straight-line roadway segment for each roadway segment/receiver combination. The user, therefore, does not achieve any increase in prediction accuracy but does increase computing time by modeling a straight

line roadway by a series of straight line roadway segments.

The present version of the highway traffic noise prediction code described in this manual can consider a maximum of 3000 roadway segment/receiver combinations. The utility of the prediction code is exhibited by its capability to handle source-receiver geometries in a three-dimensional space.

3.1.3 Basic Geometric Description

The highway traffic noise prediction code described in this manual utilizes points, straight line segments, and vertical planes to model the source-receiver geometry defined by the user. All curves must be approximated by straight line segments.

The geometric description is based upon an orthogonal (x, y, z) coordinate system. The (x,y) plane (z=0) forms a horizontal reference surface (parallel to sea level) from which all elevations are measured.

Points in the (x,y,z) coordinate system are defined by the three numbers corresponding to the x-, the y-, and the z-coordinates of the point. Two points are required to define a straight line or a straight line segment. The straight line segment is the portion of the straight line between the two points defining the straight line.

The only surface recognized by the prediction code is a vertical plane (parallel to z-axis) defined by a straight line segment representing the top or most highly elevated edge of the plane such as the top edge of a barrier. The bottom edge of a vertical plane is not defined by the prediction code.

The user should refer to Appendix A for a detailed discussion of the geometric parameters associated with each element of the traffic noise prediction code. Basically, the geometric formulation of each element is as follows:

- Roadway Segments are represented by straight line segments in (x,y,z) coordinate space.

- Barriers or vertical surfaces are defined by a straight line segment representing the most elevated edge of the barrier or vertical surface in (x,y,z) coordinate space.
- Trees or shrubbery (absorptive ground strips) are defined by a straight line segment and a width (rectangular patch) in (x,y,z) coordinate space with the straight line segment representing the approximate elevation of the base of the trees or shrubbery (See Section 3.3.2 and Appendix A).
- Receivers are defined by points in (x,y,z) coordinate space. For convenience, the user may define all receivers at local ground elevation and then uniformly elevate all receivers a constant value as specified by the user.

The highway traffic noise prediction code described in this manual does not allow the (x,y) plane intersection of roadway segments with either barrier segments or absorptive ground strips. If such intersections occur for a set of input data, the program will stop execution. This check on intersection is accomplished immediately upon reading input data so that computation time is not wasted if the input data attempts to model such intersections. In this case, the user must define two separate barriers or ground strips on either side of the roadway. Similarly, the prediction code does not allow the (x,y) plane location of receivers on either roadway segments, barrier segments, or line segments defining absorptive ground strips. Generally, the prediction code considers points and/or line segments to be "close" if the distance is less than two feet.

All lengths utilized by the version of the prediction code described in this manual are in units of feet.

3.1.4 Basic Formulation of Problems

To utilize the highway traffic noise prediction code described in this manual, the user must be able to define the traffic flow on a roadway, the site geometry and acoustic characteristics, and decide which locations are to be used to obtain sound level estimates. As a general rule, the description of the site geometry and acoustic characteristics will be the more difficult task of the three basic steps. A detailed discussion of the characterization of the traffic

noise source, the site geometry (propagation path), and receiver location (sound level prediction) follows.

First, the user must determine the appropriate geographic size to be utilized in conducting highway traffic noise predictions within the limitations of program size as defined by the present version of the prediction code (See Section 3.1.1 and Appendix B). Generally, rather flat sites with essentially straight roadway alignments will not utilize the full capacity of the prediction code whereas the limit of 15 receiver locations may form a limit to the geographic extent of the site to be modelled. For sites with rolling hills and curving highway alignments, the limitations on the number of allowable roadway segments or barrier segments may dictate that a large site be divided into problems of smaller geographic extent. In either case, the user must utilize engineering judgement.

The version of the highway traffic noise prediction code described in this manual is presented in a double precision format to allow the user flexibility in formulating geometric coordinates without losing computational accuracy. It is also felt that the size of problems that may be formulated using the present version of the highway noise prediction code is quite adequate for most user applications.

3.2 NOISE SOURCE CHARACTERIZATION

The present version of the highway traffic noise prediction code utilizes a roadway (possibly comprised of ten (10) straight line segments) as the basic noise source. A roadway is defined by the traffic flow conditions specified by the user and by the roadway segments describing the geometric location of the roadway. Each roadway segment carries the traffic flow conditions defined for the roadway.

3.2.1 Definition of Roadway

The definition of a roadway for the highway noise prediction code requires the user to specify the traffic flow conditions up to a maximum of five different conditions and to consider the relative distance of the receivers from the roadway.

For a receiver located far from a multi-lane highway without ramps, the user may locate a single roadway by assigning the total traffic flow to the roadway and obtain sufficiently accurate predictions. For a receiver located near to a multi-lane highway, each parallel traffic lane should be described individually. If the user requires more than the maximum number of five traffic flow conditions for a single roadway geometric alignment, the prediction code allows for the difinition of different roadways with the same geometric alignment. Hence, the user can specify as many traffic flow conditions as desired to describe a site within the limit of ten roadways total. Each roadway may be geometrically described by up to ten (10) straight line segments (See Section 6). If it is necessary to use more than ten roadway segments to describe the roadway alignment, the user should define additional roadways, as might be appropriate, to continue the roadway description.

3.2.2 Definition of Traffic Flow Conditions

The traffic flow conditions form the basis for the definition of a roadway. The highway traffic noise prediction code described in this manual utilizes a vehicle type,its speed (expressed in miles per hour), and its hourly traffic volume (vehicles per hour) to define a traffic flow condition. Hence, the user is required to determine the operating speed and the hourly traffic volume by vehicle type to define the roadway.

The prediction code defines three vehicle types to model traffic flow conditions based upon the noise emission characteristics of each vehicle type. The code-defined vehicle types all consider the vehicle noise emissions as a function of vehicle speed. Also, the user may define an additional vehicle type by specifying a speed-independent overall A-weighted vehicle emission level and, if required, an A-weighted vehicle emission octave band spectra.

The vehicle types defined by the present version of the highway traffic noise precition code are as follows:

- Type 1 Vehicle (Automobiles and Light Trucks): All vehicles with two axles and four wheels designed primarily for transportation of nine or fewer passengers (automobiles) or for transportation of cargo (light trucks). Generally, the weight is less than 10,000 pounds.
- Type 2 Vehicle (Heavy Trucks): All vehicles having three or more axles and designed for the transportation of cargo. Generally, the gross vehicle weight is greater than 26,000 pounds.
- Type 3 Vehicle (Medium Trucks): All vehicles having two axles and six wheels designed for the transportation of cargo. Generally, the gross vehicle weight is greater than 10,000 pounds but less than 26,000 pounds.
- Type 4 Vehicle (User Defined): The noise emission characteristics of the Type 4 vehicle are defined by the user to include an additional vehicle type not appropriate to the Type 1, Type 2, or Type 3 vehicles defined above. The present version of the highway traffic noise prediction code noes not allow the Type 4 vehicle emission levels to be defined as a function of vehicle speed. This restriction can be easily removed by the user as described in Appendix E: Subroutine INPUT.

A detail discussion of the noise emmission levels and standard deviations of the noise emission levels for each vehicle type and the speed dependent description of the overall A-weighted sound level and the A-weighted octave band levels is presented in Appendix A, Section A.2.

Additionally, the user must specify a noise source height adjustment for each vehicle type to represent an effective height above the roadway from which the vehicle's noise may be considered to originate. Proper selection of the source height adjustment is particularly important for situations in which barriers are located near the roadway since the higher the noise source elevation above the roadway, the less effective is a barrier of fixed height. A source height adjustment

of 0.0 feet is recommended for Type 1 vehicles (automobiles and light trucks) whereas an adjustment of 8.0 feet is recommended for Type 2 vehicles (heavy trucks) to simulate location of noise emissions from exhaust stacks. Once a source height adjustment is specified for a vehicle type, the adjustment is applied to all roadways for which the vehicle type is declared by the user.

Unless measurements are available, it is recommended that the Highway Capacity Manual, 1965 (10) be used to determine the average operating speed from the hourly traffic volume assumed for the vehicle type.

3.2.3 Roadway Segment Definition

A roadway segment, as considered by the prediction code, is used only to model a roadway alignment as a series of straight line roadway segments. It is good practice from the standpoint of computation time to use as few roadway segments as may appear practical to define a roadway alignment. If in doubt, however, the user should approximate the roadway alignment as accurately as possible. If a roadway is straight, the user should define the roadway by a single roadway segment. There is no increase in prediction accuracy associated with an increase in the number of roadway segments provided that the roadway alignment can be modeled as a straight line. The judgment as to how many roadway segments are appropriate to define a roadway alignment must be left to the user.

3.3 SITE GEOMETRY AND ACOUSTIC CHARACTERIZATION

The characterization of the site model comprising roadway location, topography, foliage, barriers, buildings, etc. is discussed in this section. The highway traffic noise prediction code described in this manual utilizes only line segments and vertical planes to characterize site geometry. Acoustic propagation path characterization is modeled by the code using diffraction over and reflection from vertical surfaces and absorption.

3.3.1 Site Topographic Characterization

As described in Section 3.2, the highway traffic noise source is geometrically defined by a roadway comprising up to ten straight line roadway segments. The site topography away from the highway source is modeled by the prediction code using the diffraction and surface reflection characteristics of a thin screen barrier (See Appendix A, Sections A.6 and A.8). The thin screen barrier is defined as a vertical plane. Hence, the prediction code does not recognize a continuous ground surface for the site, but approximates the site topography using vertical surfaces.

The computer considers only the strongest diffraction of sound from the highway source to the receiver for the case of multiple barrier diffraction, Hence, the user need only to define the maximum elevation of a ridge line or hill, for example, between the highway and the receiver. Usually, site topography will be modeled as an absorptive barrier; however, if the user decides that reflections may be important reflective barriers may also be utilized. This decision must be based upon the relative geometry of the highway, the topographic features being modeled, and the receiver locations.

3.3.2 Site Vegetation Characterization

The highway traffic noise prediction code considers only the excess attenuation expected by either low ground cover or high ground cover representative of either shrubbery or tall trees. (See Appendix A, Section A.7).

Both low and high ground cover are defined by the user as a rectangular patch or strip comprising a centerline (two end points) and a width. The centerline of the patch is located at ground elevation. Low ground cover (shrubbery) is defined by the code as ten (10) feet high above the patch centerline and high ground cover is defined as 30 feet high above the patch centerline. If the direct ray from a source location on a roadway segment to the receiver passes over 10 feet above the centerline for low ground cover or over 30 feet above

the centerline from high ground cover, the code ignores the attenuation resulting from the ground cover in calculating the acoustic intensity at the receiver. Also, if a diffraction of a ray from the source to the receiver is encountered, the attenuation resulting from the ground cover is ignored completely.

In considering the problem of diffraction and ground cover attenuation and whether or not the effect of ground cover will be included or ignored, the prediction code will be dealing with a sub-segment of the user-defined roadway segment. Hence, the prediction code will not be excluding ground cover effects from the basic problem being executed unless diffraction is encountered for the entire roadway segment/receiver geometry (See Section 3.1.2).

3.3.3 Definition of Barriers

The highway traffic noise prediction code described in this manual models a barrier using Fresnel diffraction theory (See Appendix A, Section A.6). The top edge of a barrier is defined by up to ten (10) straight line segments. Each straight line segment defines a thin vertical plane through which sound cannot be transmitted. The prediction code allows the user to define a maximum of 20 barriers total to describe the site. The user must define each barrier as being either acoustically absorptive or reflective. As defined by the prediction code, absorptive barriers are pure acoustical absorbers (unit absorption coefficient) whereas reflective barriers are pure acoustical reflectors (zero absorption coefficient). The absorptive barrier will be used most often to define site topography whereas the reflective barrier can be used to model hard vertical surfaces such as the exterior sides of a building. Absorptivity and reflectivity characteristics apply to both sides of a barrier.

The obvious use of the barrier model defined by the prediction code is that of highway noise abatement design. As described in Appendix A, Section A.6, the barrier attenuation model used by the prediction code does not consider either the effect of diffraction

around the ends of a barrier on the additive effect of multiple diffraction over several barriers between the source and the receiver. In the latter case, the prediction code uses only the single most effective diffraction encountered in the path from the source to the receiver. Barrier attenuation is limited to a maximum of 20 dB by the prediction code (See Appendix A, Section A.6).

3.3.4 Definition of Reflectors

The present version of the highway traffic noise prediction code described in this manual allows the user to define vertical reflective surfaces using the barrier model with reflective acoustic characteristics. This feature may be useful if either a receiver location is at a distance from a reflective surface or if one desires to estimate traffic noise levels on a building surface (a receiver cannot be located on or on top of a barrier so place receiver locations typically at 1 foot from the barrier surface).

Reflections of traffic noise can cause increases in receiver sound levels that are significant. The prediction code does not consider either effects of frequency or correlation between direct and reflected acoustic intensity at the receiver. Hence, the maximum effect on predicted sound levels resulting from reflection will be 3 dB which will occur only at locations very near to a reflective surface.

In order to be considered in the summation of the acoustic intensity at a receiver, the prediction code utilizes a criterion by which to judge the significance of the reflections from 11 different reflectors during each step in the computational procedures. If more than 11 reflections are encountered, the prediction code stops execution, prints an error message, and reads the next data set (See Section 5.6).

3.4 RECEIVER LOCATION AND PREDICTED RESULTS

The highway traffic noise prediction code described in this manual allows the user to specify, up to a maximum number of 15 points (receiver locations) at which traffic noise predictions are computed for a single data set. To specify the desired predicted sound level

estimates, the user can specify either frequency-weighted overall sound level descriptors or frequency-weighted overall and octave band sound level descriptors.

3.4.1 Receiver Locations

Receiver locations or noise prediction points may be defined anywhere desired by the user provided that the receiver is not on a line segment defining a roadway, a barrier, or a ground strip. Since the prediction code does not define a ground surface, the user must ensure that a receiver location is physically achievable. The prediction code allows the user to define a receiver height adjustment that automatically shifts all receiver elevations by the specified distance. The receiver height adjustment is useful in that receiver locations may be initially placed at local ground elevations and then elevated a uniform distance. It is common practice to use 5 feet for ear height and 10 feet per building storey as appropriate elevations above local ground level.

3.4.2 Predicted Results

The highway traffic noise prediction code described in this manual estimates several sound level descriptors useful to highway planners and designers. Basically, the user has the option of whether or not the calculations of the energy averaged A-weighted octave band sound levels are to be performed.

The utility of the energy-averaged A-weighted octave band sound levels is important only if the user requires <u>interior</u> sound level estimates for buildings to determine traffic noise impact. The prediction code can provide the averaged exterior A-weighted octave band sound level estimates to achieve this goal. Since the prediction code calculates the overall A-weighted energy mean level and standard deviation independently of any spectral calculations, the user does not achieve significant prediction accuracy by calculating the octave band levels. If spectral calculations are desired, the prediction code conducts the calculations for <u>all</u> receivers. To emphasize the difference in number computations, for the present size of the prediction code, the user could define 3000 basic problems as described

in Section 3.1.2 and obtain the maximum number of 15 overall sound level estimates. However, if one requested calculations for all octave bands each basic problem would be conducted essentially eight more times for approximately 24,000 additional analyses or a total of 27,000 analyses to obtain the 15 octave band spectra.

The prediction code always calculates the energy mean A-weighted overall sound level and standard deviation. However, if the user requests all eight octave band calculations, the value of the energy mean level printed is the energy average of the octave band spectra rather than the independent overall calculated value.

This aspect of the prediction code output procedure is discussed since the user may note slight differences (usually less than 1dB) between the estimated value of the energy mean level whether or not the octave band calculations are requested. This output procedure is utilized so that the user will achieve consistent results between the overall A-weighted energy mean level and the A-weighted octave band levels. The prediction code always prints the independently calculated value for the averaged standard deviation.

The traffic noise descriptors predicted by the code are as follows:

- LE(A) - Energy mean A-weighted sound level (See Appendix A, Equation (A-10)).
- L90 - The A-weighted sound level exceed 90% of the time (See Appendix A, Equation (A-34c))
- L50 - The A-weighted sound level exceeded 50% of the time (See Appendix A, Equation (A-34b))
- L10 - The A-weighted sound level exceeded 10% of the time (See Appendix A, Equation (A-34a)).
- SIGMA - The intensity averaged value of the standard deviation of the composite traffic noise level (See Appendix A, Equation (A-33)).

The present version of the highway traffic noise prediction code does not calculate the noise pollution level; L_{NP}, however, the user can obtain this parameter by coding Equation (A-32) and

modifying the appropriate output statements in the MAIN program (between statement numbers 56 and 60) if desired. The prediction code output format is presented in Section 7.

4. FEATURES OF THE PREDICTION CODE

The version of the TSC highway traffic noise prediction code described in this manual features several important modifications from the 1974 version (5). The modifications relate to the vehicle emission levels, excess attenuation, and predicted results. Concerning the input data format changes, the user will note that the only change is to the data blocks describing the program initialization parameters.

4.1 VEHICLE EMISSION LEVELS

As described in Section 3.2, the present version of the highway traffic noise prediction code defines three vehicle types with the vehicle noise emission levels and the standard deviation of the levels being represented as quadratic polynomial functions of vehicle speed. Only the user-defined Type 4 vehicle utilizes speed-independent values of noise emission levels and standard deviation. All values of sound level and standard deviation are defined for an A-weighted overall level and for A-weighted octave band levels. Previous versions of this prediction code allowed speed-dependence of vehicle noise emission characteristics only for automobiles (Type 1 vehicles). Further, previous versions of this prediction code did not allow the user to define a medium truck (Type 3 vehicle) category to model the vehicle mix on a roadway. Differences in predicted traffic noise levels between the present version and previous versions of this code for identical problems will be noted by the user. It is expected that the present version of the code will accurately predict lower values than previous versions of the code for identical problems.

4.2 ATTNEUATION DUE TO BARRIERS, SHRUBBERY, AND TREES

Based upon field experience, the present version of the highway traffic noise prediction code has decreased the maximum allowable attenuation values for barriers, shrubbery and trees. Compared to previous versions of the TSC highway noise prediction code, the present version specifies the following maximum allowable attenuations:

Barriers: Attenuation limited to 20 dB. (Previous versions placed a limit of 24 dB maximum.)

Shrubbery and Trees: Attenuation limited to 20 dB maximum total. (Previous versions placed a limit of 30 dB maximum total attenuation.)

Atmospheric Absorption: No change.

4.3 PREDICTED RESULTS

Differences in predicted traffic noise levels between the present version of the code and previous versions will be noted by the user. As discussed in Section 4.1 both the speed dependence on vehicle noise emission characteristics and the inclusion of a medium truck (Type 3 vehicle) category are expected to improve the prediction accuracy Generally, one would expect lower sound levels to be predicted by the present version of the code -- especially for receivers influenced predominantly by noise from traffic flows comprising medium and heavy trucks.

As noted in Section 3.4.2, the calculation and printing of the noise pollution level has been deleted from the present version of the prediction code.

The structure of the present version of the highway noise prediction code allows the user to modify the code to include speed-dependence for the user defined Type 4 vehicles. These modifications are described in Appendix A; Subroutine INPUT (See Appendix A, Section A.2).

5. NOTES ON FORMULATING PROBLEMS

This section of the user's manual describes notes on furmulating problems using the present version of the highway traffic noise prediction code. These notes generally refer to details of accurate modelling of the traffic noise prediction scenario and apply as well to previous versions of the prediction code. Many of these notes have been previously discussed and are reiterated in this section both for the user's convenience and for reinforcement of the concepts involved.

5.1 ROADWAYS AND ROADWAY SEGMENTS

The prediction code describes a roadway by the traffic flow conditions defined for the roadway. Each roadway may be defined by a maximum number of five different traffic flow conditions. The prediction code allows a maximum number of twenty (20) roadways to be defined. The prediction code allows roadways to intersect or to coincide geometrically.

The alignment of each roadway is defined by a connected series of straight line roadway segments. No increase in prediction accuracy is achieved by defining a straight line roadway by a series of straight line roadway segments. Computing time is directly related to the number of combinations of roadway segment/receiver configurations.

5.2 TRAFFIC FLOW CONDITIONS

The prediction code describes a traffic flow condition as a combination a vehicle speed and vehicle traffic capacity for each of the four vehicle types recognized by the code. Vehicle speed is expressed in miles per hour and vehicle traffic capacity is expressed as the number of vehicles per hour. Hence, the predicted energy mean levels and percentile levels are associated with an hourly time period.

Each roadway is defined by a maximum number of five traffic flow conditions for each roadway. A roadway can be used to model a multi-lane highway using the geometric mean distance from source to

receiver, $\sqrt{d_n d_f}$, based upon the near lane (d_n) distance and the far lane distance (d_f) as the user might deem appropriate.

It is difficult to state guidance as to which traffic flow combinations may result in the "worst hour" sound levels at a receiver, especially for multi-roadway models. Generally, traffic flow mixes comprising a significant percentage of heavy trucks moving at high speed result in higher sound levels. Reference (11) may be helpful in judging the relationship of sound levels to mixed traffic flow conditions.

5.3 DIFFRACTION OF SOUND

The prediction code considers only the most effective diffraction of sound from a subsegment of a roadway segment to a receiver for source-receiver paths containing multiple diffractions (i.e., barriers). The user should attempt to recognize this characteristic so that the available number of barriers that can be defined (twenty maximum in the present version of the code) are utilized efficiently. For example, a barrier placed on top of a berm should be modeled as a single barrier at the maximum elevation points rather than as two barriers.

The prediction code defines a barrier by its top edge and does not recognize a bottom edge for the barrier. For example, a barrier defined for an elevated highway is simply a high screen from the defined top edge to the imaginary ground level.

The top edge of a barrier may be defined by up to a maximum number of ten (10) straight line segments. Barriers may intersect themselves or other barriers. Barriers may be specified as perfectly reflective or perfectly absorptive acoustically. The reflectivity or absorptivity acoustic characteristics of a barrier apply to both sides of the barrier.

Barriers are not allowed to intersect roadways. Barriers may, however, intersect absorptive ground strips. Effects of acoustic diffraction around the end of a barrier is ignored by the prediction code.

5.4 SHRUBBERY AND TREES

The prediction code describes shrubbery and trees by a straight centerline and a width defining a rectangular patch of absorptive ground cover. Shrubbery is assumed to be ten (10) feet high and trees are assumed to be twenty (20) feet high above the defined centerline.

If during the analysis of a roadway segment or subsegment a diffraction is encountered on the source-receiver path, all attenuation effects of shrubbery and/or trees are ignored for that source-receiver path. Hence, the code cannot estimate the attenuation effects of plantings on berms, for example. If the user is in doubt concerning the utility of introducing a ground strip, do so since the prediction code will make the correct judgements concerning attenuation of traffic noise. The defined centerline of an absorptive ground strip is not allowed to intersect a roadway segment. Absorptive ground strips may, however, intersect other ground strips on barriers (See Appendix A, Section A.7).

5.5 REFLECTORS

The prediction code models a reflective surface using a barrier with reflective acoustic characteristics. The user should include large buildings or other potential reflective surfaces in his site model. The prediction code is capable of defining only vertical plane surfaces. Hence, reflections from either inclined or horizontal surfaces cannot be considered by the prediction code.

The maximum increase in receiver sound levels resulting from reflections is 3 dB corresponding to an incoherent sound source. No effect of acoustic wavelength is considered. If the direct ray connecting a source point and an image receiver point intersects a barrier within two (2) feet of the top edge, reflection is ignored.

5.6 FORMULATING GEOMETRY

The highway traffic noise prediction code defines a site geometry using only straight line segments and vertical planes (barriers) described by the most elevated edge comprised of straight line segments. The code does not recognize a ground plane as such.

The user should basically attempt to define only maximum topographic elevations and should include important reflective surfaces.

It is good practice to utilize a scale plat of the site in formulating coordinates for roadways, barriers, absorptive ground strips, and receivers. Doing this will allow the user to avoid the grief and wasted time resulting from non-execution of the code as a result of a barrier or a ground strip segment intersecting a roadway. However, the present version of the prediction code will check input data for intersections prior to beginning any calculations so that computation time is not wasted.

As a rule-of-thumb, the user should locate coordinate points for barriers, absorptive ground strips and receivers no closer than two feet from a non-compatable geometric element to avoid rejection of the input data.

5.7 RECEIVER LOCATION AND PREDICTED RESULTS

The highway traffic noise prediction code allows the user to specify up to a maximum of 15 receiver locations at which sound level estimates are to be conducted. A receiver should not be located within two feet of either a roadway segment, a barrier surface, or an absorptive ground strip. Such locations may result in problems with the arithmetic for extreme geometric configurations. If the code encounters such problems, execution is stopped. The following section describes error messages printed by the present version of the highway traffic noise prediction code to assist the user in correcting illegal input data.

5.8 PREDICTION CODE OUTPUT ERROR MESSAGES

The present version of the highway traffic noise prediction code prints several error messages that assist the user in either identifying illegal input data or warning the user that an error has occured.

The error messages printed by the code and the sequence of events taken by the code in the event that an error has occured are described below. A fatal error is an error that stops execution of the code for

all data sets following that set in which the error occurs. A reject error is an error in which the code stops execution of the data set in which the error occurs but continues its attempt to execute subsequent data sets. The user should note that a reject error may result in a subsequent fatal error due to the inherent flexibility of the input data sequence allowed by the code (See Section 6). Warning messages notify the user that a non-fatal restriction on the input data or error during execution has been encountered but that the code is continuing to execute the defined problem.

5.8.1 Error Messages Occuring During Data Set Input

Prior to execution of a data set the prediction code checks the input data to see that for each vehicle type specified the vehicle speed falls within the range of 20 MPH to 70 MPH and also checks to insure that the geometric description of a roadway and a barrier included two end points.

Vehicle Speed Range Exceeded: If the user has specified a vehicle speed outside the range of 20 MPH to 70 MPH the following warning messages are printed as appropriate:

"VEHICLE SPEED SUPPLIED IS LESS THAN 20 MPH ADJUSTED TO 20"

or

"VEHICLE SPEED SUPPLIED IS GREATER THAN 70 MPH ADJUSTED TO 70"

The code continues execution with the indicated adjustments for vehicle speed for the roadway being considered (See Appendix A, Section A.2).

Illegal Definition of Roadway or Barrier: If the user has attempted to define either a roadway or a barrier by one coordinate point (two points minimum are required, See Section 6) the following fatal error messages are printed:

"INSUFFICIENT ROAD SECTIONS"

"INSUFFICIENT BARRIER SECTIONS"

If this error occurs, execution of the prediction code stops. The user should correct the appropriate input data.

5.8.2 Error Messages Occuring During Check of Input Data

Subsequent to reading the input data, but prior to execution of sound level calculations, the prediction code checks to see if either a barrier segment or the centerline of an absorptive ground strip intersects a roadway segment. The code checks for such intersections using only the x-y coordinates of the line segments so the user can prevent such errors by using a scale plat of the site to formulate the roadway segment, barrier segment, and absorptive ground strip coordinates. If such an intersection occurs the following reject error messages are printed as appropriate:

"ILLEGAL BARRIER INTERSECTS ROADWAY R XX RS XX BXX BSXX"

where R XX denotes roadway number XX

RS XX denotes roadway segment number XX

B XX denotes barrier number XX

BS XX denotes barrier segment number XX

"ILLEGAL GROUND STRIP INTERSECTS ROADWAY R XX RS XX AGS XX"

where R XX denotes roadway number XX

RS XX denotes roadway segment number XX

AGS XX denotes absorptive ground strip number XX

These reject error messages are printed for each intersection encountered in the input data for both barrier segments and absorptive ground strips. Hence, if illegal intersections are encountered, all such illegal data will be displayed to the user. Upon completing the data check, the code stops execution of the data set containing illegal intersections of roadway segments with barrier segments and/or ground strips and attempts to read the next data set.. The user should check and correct the input data.

5.8.3 Error Messages Occuring During Sound Level Calculations

The highway traffic noise prediction code checks for illegal operations during execution of subroutine GEOMRY. As described in Appendix E, subroutine GEOMRY conducts the calculations associated with the basic problem considered by the prediction code (See Section 3.1.2). Two basic types of errors can occur that are internal to the code in Subroutine GEOMRY: attempting to shift a point on a zero length line

segment or encountering too many reflections at a receiver. The error messages are as follows:

"*** ANGLE SUBTENDED AT RECEIVER BY ROAD SEGMENT IS APPROACHING ZERO
INITIAL PT. OF ROAD SEGMENT (COORDINATES)
END PT. OF ROAD SEGMENT (COORDINATES)
RECEIVER POINT (COORDINATES)

This message is a warning statement and the code continues execution.

"ERROR IN MOVE"

This a reject error message indicating that the subroutine MOVE has attempted to shift a point on a line segment of zero length. The user should check the input data for roadway segments and barrier segments. The code halts execution and proceeds to the next data set.

"ERROR IN MOVE2"

This is a reject error message indicating that the subroutine MOVE2 has attempted to shift a point on a line segment of zero length (in the x-y plane). The user should check the input data for roadway segments and barrier segments. The code halts execution and proceeds to the next data set.

If the maximum allowable number of reflections (eleven) is exceeded at a receiver, the code halts execution and prints the following message:

TOO MANY REFLECTIONS RCV XX R XX S XX

where RCV XX is receiver number XX
R XX is roadway number XX
S XX is roadway segment number XX

The user should check the receiver location in relation to the reflective barriers defined for the problem to see if simplifications in the site model are possible.

6. INPUT DATA REQUIREMENTS

The version of the highway traffic noise prediction code described in this manual differs only slightly from previous versions of the code with respect to input data requirements. Specifically, the user no longer specifies a constant value for the standard deviation of the code-defined vehicle types since this parameter is now calculated as a function of vehicle speed and frequency.

The following step-by-step instructions are provided to assist the user in formatting input data to the computer program.

6.1 INPUT DATA FORMAT AND DATA BLOCK SEQUENCE

6.1.1 Input Data Format

The prediction code accepts input data from a card reader. Three types of input data format are allowed by the code:

- Integer Format - A fixed point number written without a decimal point. All integers must be right - justified within the allotted field of the input card.
- Real Constant - A floating point number written with a decimal point. Normally, the real number may be situated anywhere within its allotted field on the card.
- Alphanumeric - Any combination of alphabetic and numeric characters. Alphanumeric data may be located anywhere within the allotted field on a card.

6.1.2 Data Block Sequence

The first card in a data set read by the program is a title card containing arbitrary alphanumeric descriptive information in columns 2 through 60. Following the title card up to five blocks of data may then follow in an arbitrary sequence. Each data block is identified by an index as follows:

Index	Data Block
1	Program Initialization Parameters
2	Roadway Parameters
3	Barrier Parameters
4	Ground Cover Parameters
5	Receiver Parameters.

Each data block is preceded by a control card containing the data block index in column 5. The end of a data set is denoted by a control card with the integer 6 in column 5.

Multiple data sets may be run in sequence with each data set being initiated by the title card and ended by the control card with the integer 6 in column 5. Once a data set has been defined for execution of multiple data sets, it is sufficient to modify only the data blocks in the previous data set, as required, to define the new data set. Any data blocks not redefined by the new data set will remain unchanged from that in the preceeding problem.

The first data set must specify, as a minimum, the following data blocks:

1 Program Initialization Parameters
2 Roadway Parameters
5 Receiver Parameters

If either the barrier parameter data block or the absorptive cover ground cover data block are omitted for the first data set, all calculations involving barriers or ground cover are bypassed by the code. Subsequent to the execution of the first data set, the user may redefine any data block desired to create a new problem. Any data blocks unchanged will maintain their initial values in subsequent data sets.

6.2 PROGRAM INITIALIZATION PRARMETERS

The data block containing the program initialization parameters is preceeded by a control card with the integer 1 in column 5. Following the control card, six or nine cards are used to complete the program initialization parameter data block.

The following five parameters must be specified in the indicated sequence with the parameter value entered as a real constant in columns 1 through 10 and the parameter index indicated as an integer in column 15.

Parameter (Real Constant: Cols. 1 through 10)	Parameter Index (Integer: Col. 15)
Receiver Height Adjustment	1
Number of Frequency Bands	2
Source Height Adjustment for Passenger Cars	3
Source Height Adjustment for Heavy Trucks	4
Source Height Adjustment for Medium Trucks	5
Source Height Adjustment for New Vehicles	6

If desired, the user may include alphanumeric information in columns 37 through 80 for convenience or specific information on each of the above cards. If no alphanumeric data is entered, the above titles will be printed by the code to identify the parameters in the output listing. If the user does not desire to define a "new" vehicle, column 20 of the medium truck source height adjustment must contain the letter L denoting the last card in the data block. (See Section 3.2.2)

If the user defines a "new" (Type 4) vehicle, omit the "L" in column 20 of the source height adjustment data card for medium trucks and include the source height adjustment for "new" vehicles as a real constant between columns 1 through 10; the parameter index, 6, in column 15; the letter L in column 20; and desired alphanumeric information in columns 31 through 80. Two cards are then used to define the vehicle speed-independent values of the sound level spectrum and the spectrum of the standard deviations of the sound levels. The first card following the source height adjustment for the Type 4 vehicle specifies the sound level spectra. The second card following the source height adjustment for the Type 4 vehicle specifies the spectra for standard deviations. Each of these cards contains nine real constants located in columns 1 through 5, 6 through 10, 11 through 15, etc. The constant in columns 1 through 5 corresponds to the overall A-weighted level or overall standard deviation of the A-weighted level and each subsequent number corresponds to the octave band center frequencies from 63 Hz, to 8000 Hz inclusive. The user needs to define only the overall A-weighted level and standard deviation and the A-weighted octave band values consistent with the user-defined value of the number of frequency bands specified in the program initialization parameters.

The user is reminded that the overall A-weighted sound level calculations are independent of the octave band calculations (See Section 3.4.2).

6.3 ROADWAY PARAMETERS

The data block containing the roadway parameters is preceeded by a control card with the integer 2 in column 5 and another integer in columns 6 through 10 to indicate the number of roadways defining the site. (The present version of the highway traffic noise prediction code allows the user to define a maximum number of 20 roadways.)

For each roadway, the user must specify a data block defining the traffic flow conditions on the roadway and the geometric alignment of the roadway. To define the traffic flow conditions for a roadway, the user may define up to a maximum number of five (5) combinations of vehicle flow rate, vehicle speed, and vehicle type.

For each traffic flow condition on a roadway, the user specifies (using two real constants) the traffic flow rate in vehicles per hour in columns 1 through 10 and the mean vehicle speed in miles per hour in columns 11 through 20, vehicle type is specified using an integer 1 through 4 in column 25. One card is used to specify each traffic flow condition up to a maximum of 5 cards per roadway. For the last card defining a traffic flow condition for a roadway, the user must specify the letter "L" in column 31. (See Sections 3.2.2 and 5.2).

Following the data cards defining the traffic flow conditions on a roadway, the user must define the straight line roadway segments specifying the roadway alighment. For each point defining an end point of a roadway segment the user specifies the x-coordinate in columns 1 through 10, the y-coordinate in columns 11 through 20, and the z-coordinate (elevation) in columns 21 through 30. Each coordinate value is specified as a real constant expressed in units of feet. The end points of each segment are specified on one card each, sequentially, beginning with the initial point defining the roadway. Each roadway alignment may be approximated by up to ten (10) straight line

segments (eleven points or data cards). See Sections 3.2.3 and 5.1.

The number of data blocks specifying roadways must correspond to the number of roadways specified on the control card for roadway parameters.

6.4 BARRIER PARAMETERS

The data block containing the barrier parameters (i.e., potential diffractions of sound) is preceeded by a control card specifying the integer 3 in column 5 and a right-justified integer in columns 6 through 10 specifying the number of barriers. The user may define a maximum of 20 barriers using the present version of the highway traffic noise prediction code. As discussed in Sections 3.3, 5.3, and 5.5, the user defines barriers to model site topography, noise abatement barriers, and buildings. The top contour of a barrier is approximated by a sequence of straight line segments. Each barrier segment is assumed to be totally impervious to sound transmission through the barrier. The coordinates of points specifying the top of the barrier are defined utilizing the same format as that for roadway segments (See Section 6.3). The last card (coordinate point) defining a barrier contains in addition to the three real constants defining the point either the letter A (absorptive barrier) or the letter R (reflective barrier) in column 31. The user must define one set of barrier coordinates for each of the total number of barriers specified in the control cards.

The letter A in column 31 of the last card defining a barrier indicates that the preceeding points describe an obstacle that reflects sound weakly and can hence be approximated by a totally sound absorptive surface. This acoustic characteristic applies to both sides of the barrier. See Sections 3.3 and 5.3.

The letter R in column 31 of the last card defining a barrier indicates that the preceeding points describe an obstacle that totally reflects sound. The prediction code considers reflections from vertical surfaces only. See Sections 3.3 and 5.5.

Barrier segments are not allowed to cross a roadway segment.

6.5 GROUND COVER PARAMETERS

The data block containing the ground cover parameters is preceeded by a control card containing the integer 4 in column 5 and a second integer right-justified in column 6 through 10 indicating the total number of absorptive ground strips defined for the data set. The areas defining absorptive ground strips are specified by the centerline and the width of the rectangular patch. Two data cards are required to describe each ground strip. The first data card contains the x-, y-, and z-coordinates of one end point defining the centerline and the width of the strip in sequence. These four numbers, in the indicated sequence, are specified as real constants in the fields between columns 1 through 10, 11 through 20, 21 through 30, and 31 through 40. The second card contains the x-, y-, and z-coordinates of the end point defining the centerline between columns 1 through 10, 11 through 20, and 21 through 30, respectively. Following these three real constants, the user specifies the letter G (low ground cover) or the letter T (high ground cover) in column 31.

The letter G in column 31 of the second data card defining a ground strip identifies the ground strip as high grass or shrubbery and the letter T in column 31 identifies the ground strip as trees. The computer code checks to see that the centerline defining a ground strip does not cross a roadway segment. The user, however, should ensure that the defined ground cover <u>strip</u> does not intersect a roadway especially if one is attempting to define a wide strip. (See Sections 3.3 and 5.4).

6.6 RECEIVER PARAMETERS

The data block containing the receiver parameters (location) is preceeded by a control card with the integer 5 in column 5 and a second integer right-justified in columns 6 through 10 to indicate the total number of receivers defined for the data set. Each receiver location is defined by a single data card specifying the x-, y-, and z-coordinates as real constants in the fields between columns 1 through 10, 11 through 20, and 21 through 30, respectively. The present

version of the highway traffic noise prediction code allows the user to define up to 15 receiver locations. Each z-coordinate value specified on a receiver location data card will be altered by the value specified for the receiver height adjustment in the program initialization parameters.

The prediction code does not explicitly check for receiver locations on a line segment defining a roadway, an absorptive ground strip centerline on a vertical plane defining a barrier segment. However, such locations would cause the code to attempt the consideration of a zero distance between the receiver location point and a line segment or plane which would result in one of the error messages described in Section 5.8.3. As a rule-of-thumb, the user should always specify receiver locations two feet away from a line segment defining a roadway or ground strip centerline or from a vertical plane specifying a barrier segment.

At each receiver location the highway traffic sound level predictions will be computed as specified by the number of frequency bands defined in the program initialization parameters. If the number of frequency bands requested is specified by the integer 1 only the overall A-weighted sound level descriptors are calculated. If the number of frequency bands is specified by an integer between 2 and 9, the appropriate A-weighted octave band levels beginning at 63 Hz will be calculated up to the band index specified. See Sections 3.4 and 5.7.

7. EXAMPLE PROBLEMS

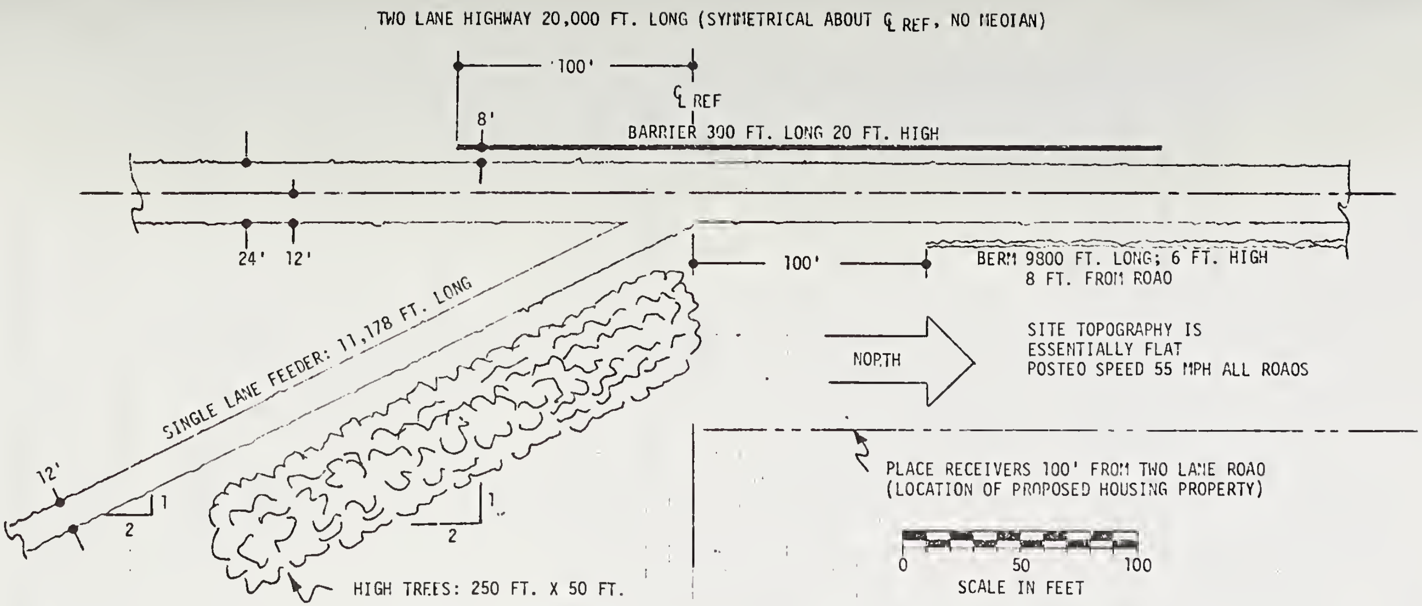
This section of the highway traffic noise prediction code users manual presents an example problem illustrating the translation of site information into the input data format recognized by the code and an illustration of the output data format utilized by the code. This example problem is identical to that described in report number DOT-TSC-FHWA-72-1, "Manual for Highway Noise Prediction" (1). The differences between the predicted values using the present version of the code as described in this section and values obtained by the previous versions of the prediction code are discussed in Section 7.4.

7.1 SITE DESCRIPTION FOR EXAMPLE PROBLEMS

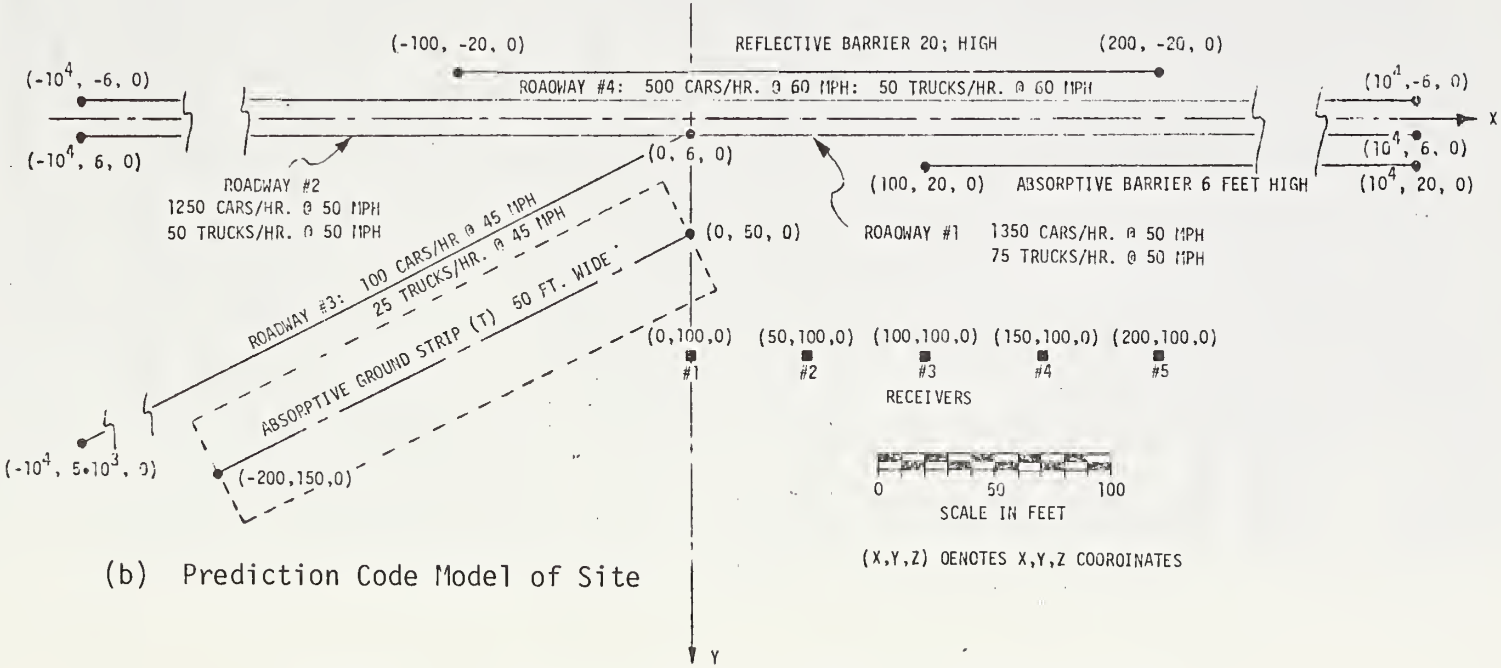
Figure 7-1 illustrates a highway situation comprising a two lane highway and a single feeder lane joining the highway. The lane widths are 12 feet with no median strip for the two lane highway. Except for a six (6) foot high earth berm located on the north-eastern edge of the two lane highway the site topography is essentially flat. A 20 foot high barrier is located along the western edge of the roadway and a stand of trees is located along the feeder lane. It is desired to evaluate the sound levels in the north-eastern quadrant of the site at 100 feet from the highway centerline.

It is decided to evaluate the receiver sound levels for alternate site configurations as follows:

- Configuration 1, site as described above with a reflective barrier surface,
- Configuration 2, site as described above with an absorptive barrier surface,
- Configuration 3, site as described in Configuration 2, without the stand of trees adjacent to the feeder lane,
- Configuration 4, site as described in Configuration 3, with the code-defined heavy truck (Type 2) vehicle replaced by a user-defined (Type 4) vehicle.



(a) Site Plat With Field Notes



(b) Prediction Code Model of Site

FIGURE 7-1. SITE PLAT AND SITE MODEL FOR EXAMPLE PROBLEM

The traffic flow parameters are determined as indicated in the site plat in Figure 7-1.

7.2 INPUT DATA FOR EXAMPLE PROBLEMS

The input data for the sample problems is indicated in Figure 7-2 using a standard coding form. The notations enclosed by asterisks are for user reference and do not constitute data. Data set 1 comprises the complete problem formulation. Data set 2 modifies data set 1 by deleting the barrier. (Since configuration 2 specifies an absorptive barrier and since no receivers are located in a site region affected by diffraction by the barrier, one can simplify the input and computation requirements by deleting the barrier). Data set 3 comprises the site configuration without the barrier or the stand of trees. Data set 3 modifies data set 2 by deleting the absorptive ground strip modeling the stand of trees. Data set 4 modifies data set 3 by replacing the code-defined heavy truck by a user defined (Type 4) vehicle.

7.3 OUTPUT DATA FOR EXAMPLE PROBLEMS

The highway traffic noise prediction code immediately prints output once the input file for a data set is read by the computer.

The heading TRAFFIC NOISE PREDICTION is printed and the input data is printed in the following order:

Title;

Program Initialization parameters for the first of a series of data sets only;

Roadway parameters are printed next in the sequence of vehicle type specifying vehicle flow rate in vehicles per hour and vehicle speed in miles per hour as specified for the roadway. Following the vehicle data for the roadway, the x,y,z coordinates of the end points of the roadway segments are printed;

Barrier parameters are printed next in sequence with the letter A or R printed in parenthesis following the barrier number. Next, the x, y, z, coordinates of the end points of the barrier segments are printed;

```
*****TITLE CARD******
SAMPLE PROBLEM 1                  (SAI MOD 12/20/76)
*****DATA BLOCK FOR PROGRAM INITIALIZATION PARAMETERS*****
    1
    5.0       1                   RECEIVER HEIGHT ADJUSTMENT
    9.0       2                   NUMBER OF FREQUENCY BANDS
    0.0       3                   HEIGHT ADJUSTMENT FOR TYPE 1 VEHICLES
    8.0       4                   HEIGHT ADJUSTMENT FOR TYPE 2 VEHICLES
    4.0       5
    3.5       6    L              HEIGHT ADJUSTMENT FOR TYPE 4 VEHICLES
 77.0 52.0 62.0 68.0 72.0 72.0 70.0 64.0 50.0
  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
*****DATA BLOCK FOR ROADWAY PARAMETERS*****
    2    4
 1350.0     50.0          1
   75.0     50.0          2     L
    0.0      6.0             0.0
10000.0      6.0             0.0  L
 1250.0     50.0          1
   50.0     50.0          2     L
-10000.0     6.0             0.0
    0.0      6.0             0.0  L
  100.0     45.0          1
   25.0     45.0          2     L
-10000.0  5000.0             0.0
    0.0      6.0             0.0  L
  500.0     60.0          1
   50.0     60.0          2     L
-10000.0    -6.0             0.0
10000.0     -6.0             0.0  L
*****DATA BLOCK FOR BARRIER PARAMETERS*****
    3    2
 -100.0    -20.0         20.0
  200.0    -20.0         20.0  R
  100.0     20.0          6.0
10000.0     20.0          6.0  A
*****DATA BLOCK FOR GROUND COVER PARAMETERS*****
    4    1
    0.0     50.0          0.0       50.0
 -200.0    150.0          0.0  T
*****DATA BLOCK FOR RECEIVER PARAMETERS*****
    5    5
    0.0    100.0          0.0
   50.0    100.0          0.0
  100.0    100.0          0.0
  150.0    100.0          0.0
  200.0    100.0          0.0
    6
```

NOTE: ** Comments enclosed by asterisks do not constitute data ***

FIGURE 7-2. INPUT DATA FORMAT FOR EXAMPLE PROBLEM (Continued)

```
*****TITLE CARD*******
 SAMPLE PROBLEM 2                           (SAI MOD 12/20/76)
        3        0
        6
*****TITLE CARD*******
 SAMPLE PROBLEM 3                           (SAI MOD 12/20/76)
        4        0
        6
 SAMPLE PROBLEM 4                           (SAI MOD 12/20/76)
        2        4
  1350.0            50.0          1
    75.0            50.0          4          L
     0.0             6.0           0.0
 10000.0             6.0           0.0       L
  1250.0            50.0          1
    50.0            50.0          4          L
-10000.0             6.0           0.0
     0.0             6.0           0.0       L
   100.0            45.0          1
    25.0            45.0          4          L
-10000.0             6.0           0.0
     0.0             6.0           0.0       L
   100.0            45.0          1
    25.0            45.0          4          L
-10000.0          5000.0           0.0
     0.0             6.0           0.0       L
   500.0            60.0          1
    50.0            60.0          2          L
-10000.0            -6.0           0.0
 10000.0            -6.0           0.0       L
        6
```

NOTE: ** Comments enclosed by asterisks do not constitute data ***

FIGURE 7-2. (Concluded)

Absorptive ground strip parameters are printed next with the letter G or T in parenthesis following the ground strip number. Next, the x, y, z coordinates of the ground strip centerline and the ground strip width are printed;

Receiver parameters are printed next in sequence giving the x,y,z coordinates of each receiver. The z coordinate value printed is the input value plus the receiver height adjustment specified in the program initialization parameters.

The above output data is a reference listing for the user giving the input data used by the code to calculate traffic noise estimates.

Following the input data listing the code then reprints the user-specified title for the problem Next, the code prints the predicted sound levels by receiver using the following format:

Receiver number and the x, y, z coordinates of the receiver.

If the user has specified the number of frequency bands to be greater than 1, the prediction code prints the title "OCTAVE BAND LEVELS (A)" with the letter A in parenthesis denoting that the values are A-weighted. Next, the octave band center frequencies are printed from 63 Hz to 8000 Hz. Under the octave band center frequencies, the prediction code lists the predicted A-weighted octave band sound pressure levels beginning at 63 Hz and ending at the upper frequency limit specified by the user.

Next, the prediction code lists the title

"LE(A) L90 L50 L10 SIGMA"

which represent the A-weighted energy mean sound level; the A-weighted sound levels exceeded 90, 50, and 10 percent of the time; and the value of the standard deviation of the sound pressure level (See Sections 3.4 and Appendix A).

The prediction code performs calculations by receiver locations considering all other parameters. Hence, if predicted results are obtained without an error message being printed, the code has completed the required sound level estimates for the indicated receiver(s).

Figure 7-3, presents the highway traffic noise prediction code output listing corresponding to the input data presented in Figure 7-2.

```
SAMPLE PROBLEM 1              (SAI MOD 12/20/76)
PROGRAM INITIALIZATION PARAMETERS
 0.500000D 01          1      RECEIVER HEIGHT ADJUSTMENT
 0.900000D 01          2      NUMBER OF FREQUENCY BANDS
 0.0                   3      HEIGHT ADJUSTMENT FOR TYPE 1 VEHICLES
 0.800000D 01          4      HEIGHT ADJUSTMENT FOR TYPE 2 VEHICLES
 0.0                   5      HEIGHT ADJUSTMENT FOR MEDIUM TRUCKS  (TYPE 3 VEHICLES)
 0.350000D 01          6      HEIGHT ADJUSTMENT FOR TYPE 4 VEHICLES
      OPTIONAL NOISE SPECTRUM
      CONSTANTS :   77.0    52.0    62.0    68.0    72.0    72.0    70.0    64.0    50.0
      STD. DEV. :    3.5     3.5     3.5     3.5     3.5     3.5     3.5     3.5     3.5
ROADWAY    1
NUMBER OF                 VEH/H         MPH
TYPE 1 VEH
   1                      0.13500D 04   0.50000D 02
NUMBER OF                 VEH/H         MPH
TYPE 2 VEH
   1                      0.75000D 02   0.50000D 02
                        SOURCE COORD IN FT
NUMBER       X              Y             Z
   1      0.0             0.60000D 01   0.0
   2      0.10000D 05     0.60000D 01   0.0
ROADWAY    2
NUMBER OF                 VEH/H         MPH
TYPE 1 VEH
   1                      0.12500D 04   0.50000D 02
NUMBER OF                 VEH/H         MPH
TYPE 2 VEH
   1                      0.50000D 02   0.50000D 02
                        SOURCE COORD IN FT
NUMBER       X              Y             Z
   1     -0.10000D 05     0.60000D 01   0.0
   2      0.0             0.60000D 01   0.0
ROADWAY    3
NUMBER OF                 VEH/H         MPH
TYPE 1 VEH
   1                      0.10000D 03   0.45000D 02
NUMBER OF                 VEH/H         MPH
TYPE 2 VEH
   1                      0.25000D 02   0.45000D 02
                        SOURCE COORD IN FT
NUMBER       X              Y             Z
   1     -0.10000D 05     0.50000D 04   0.0
   2      0.0             0.60000D 01   0.0
ROADWAY    4
NUMBER OF                 VEH/H         MPH
TYPE 1 VEH
   1                      0.50000D 03   0.60000D 02
NUMBER OF                 VEH/H         MPH
TYPE 2 VEH
   1                      0.50000D 02   0.60000D 02
                        SOURCE COORD IN FT
NUMBER       X              Y             Z
   1     -0.10000D 05    -0.60000D 01   0.0
   2      0.10000D 05    -0.60000D 01   0.0
BARRIER    1  (R)               BARRIER COORD IN FT
NUMBER       X              Y             Z
   1     -0.10000D 03    -0.20000D 02   0.20000D 02
   2      0.20000D 03    -0.20000D 02   0.20000D 02
BARRIER    2  (A)               BARRIER COORD IN FT
NUMBER       X              Y             Z
   1      0.10000D 03     0.20000D 02   0.60000D 01
   2      0.10000D 05     0.20000D 02   0.60000D 01
```

FIGURE 7-3. OUTPUT LISTING FOR EXAMPLE PROBLEM (Continued)

```
ABSORBING STRIP     1  (T)

PT          X                  Y             Z                 WIDTH
    1     0.0                0.5000D 02    0.0              0.5000D 02
    2    -0.2000D 03         0.1500D 03    0.0
RECEIVER                     RECEIVER COORD IN FT
NUMBER      X                  Y             Z
    1     0.0                0.1000D 03    0.5000D 01
    2     0.5000D 02         0.1000D 03    0.5000D 01
    3     0.1000D 03         0.1000D 03    0.5000D 01
    4     0.1500D 03         0.1000D 03    0.5000D 01
    5     0.2000D 03         0.1000D 03    0.5000D 01


SAMPLE PROBLEM 1             (SAI MOD 12/20/76)
RECEIVER                XRC          YRC           ZRC
     1                  0.0         100.0          5.0

                             OCTAVE BAND LEVELS (A)
                 63     125      250      500     1000     2000     4000     8000
                53.2    58.4     56.3     68.3     69.6     67.4     60.7     52.3

            LE(A)       L90      L50      L10     SIGMA
             74.5       63.5     70.8     78.1     5.7
RECEIVER                XRC          YRC           ZRC
     2                 50.0         100.0          5.0

                             OCTAVE BAND LEVELS (A)
                 63     125      250      500     1000     2000     4000     8000
                52.7    58.0     56.0     67.9     69.5     67.1     60.4     52.0

            LE(A)       L90      L50      L10     SIGMA
             74.2       62.6     70.2     77.7     5.9
RECEIVER                XRC          YRC           ZRC
     3                100.0         100.0          5.0

                             OCTAVE BAND LEVELS (A)
                 63     125      250      500     1000     2000     4000     8000
                51.9    57.3     55.3     67.3     69.0     66.5     60.1     51.6

            LE(A)       L90      L50      L10     SIGMA
             73.6       62.1     69.6     77.2     5.9
RECEIVER                XRC          YRC           ZRC
     4                150.0         100.0          5.0

                             OCTAVE BAND LEVELS (A)
                 63     125      250      500     1000     2000     4000     8000
                50.9    56.2     54.3     66.3     68.2     65.6     59.4     50.7

            LE(A)       L90      L50      L10     SIGMA
             72.7       62.0     69.1     76.3     5.6
RECEIVER                XRC          YRC           ZRC
     5                200.0         100.0          5.0

                             OCTAVE BAND LEVELS (A)
                 63     125      250      500     1000     2000     4000     8000
                50.0    55.3     53.4     65.4     67.4     64.8     58.8     50.0

            LE(A)       L90      L50      L10     SIGMA
             71.9       61.8     68.6     75.5     5.3
```

FIGURE 7-3. (Continued)

```
SAMPLE PROBLEM 2               (SAI MOD 12/20/76)
ROADWAY     1
NUMBER OF                   VEH/H          MPH
TYPE 1 VEH
     1                      0.1350D 04     0.5000D 02
NUMBER OF                   VEH/H          MPH
TYPE 2 VEH
     1                      0.7500D 02     0.5000D 02
                          SOURCE COORD IN FT
NUMBER        X              Y              Z
     1      0.0             0.6000D 01     0.0
     2      0.1000D 05      0.6000D 01     0.0
ROADWAY     2
NUMBER OF                   VEH/H          MPH
TYPE 1 VEH
     1                      0.1250D 04     0.5000D 02
NUMBER OF                   VEH/H          MPH
TYPE 2 VEH
     1                      0.5000D 02     0.5000D 02
                          SOURCE COORD IN FT
NUMBER        X              Y              Z
     1     -0.1000D 05      0.6000D 01     0.0
     2      0.0             0.6000D 01     0.0
ROADWAY     3
NUMBER OF                   VEH/H          MPH
TYPE 1 VEH
     1                      0.1000D 03     0.4500D 02
NUMBER OF                   VEH/H          MPH
TYPE 2 VEH
     1                      0.2500D 02     0.4500D 02
                          SOURCE COORD IN FT
NUMBER        X              Y              Z
     1     -0.1000D 05      0.5000D 04     0.0
     2      0.0             0.6000D 01     0.0
ROADWAY     4
NUMBER OF                   VEH/H          MPH
TYPE 1 VEH
     1                      0.5000D 03     0.6000D 02
NUMBER OF                   VEH/H          MPH
TYPE 2 VEH
     1                      0.5000D 02     0.6000D 02
                          SOURCE COORD IN FT
NUMBER        X              Y              Z
     1     -0.1000D 05     -0.6000D 01     0.0
     2      0.1000D 05     -0.6000D 01     0.0
BARRIER      1  (A)              BARRIER COORD IN FT
NUMBER        X              Y              Z
     1      0.1000D 03      0.2000D 02     0.6000D 01
     2      0.1000D 05      0.2000D 02     0.6000D 01
ABSORBING STRIP      1   (T)

PT            X              Y              Z                 WIDTH
     1      0.0             0.5000D 02     0.0             0.5000D 02
     2     -0.2000D 03      0.1500D 03     0.0
RECEIVER                    RECEIVER COORD IN FT
NUMBER        X              Y              Z
     1      0.0             0.1000D 03     0.5000D 01
     2      0.5000D 02      0.1000D 03     0.5000D 01
     3      0.1000D 03      0.1000D 03     0.5000D 01
     4      0.1500D 03      0.1000D 03     0.5000D 01
     5      0.2000D 03      0.1000D 03     0.5000D 01
```

FIGURE 7-3. (Continued)

```
SAMPLE PROBLEM 2              (SAI MOD 12/20/76)
RECEIVER              XRC           YRC            ZRC
   1                  0.0          100.0           5.0

                           OCTAVE BAND LEVELS (A)
            63      125     250     500     1000    2000    4000    8000
          51.8     57.0    54.9    66.8     68.3    65.9    59.2    50.9

         LE(A)     L90     L50     L10     SIGMA
          73.0     62.5    69.5    76.6      5.5
RECEIVER              XRC           YRC            ZRC
   2                 50.0          100.0           5.0

                           OCTAVE BAND LEVELS (A)
            63      125     250     500     1000    2000    4000    8000
          51.2     56.4    54.4    66.3     67.9    65.5    58.9    50.4

         LE(A)     L90     L50     L10     SIGMA
          72.6     61.4    68.8    76.1      5.8
RECEIVER              XRC           YRC            ZRC
   3                100.0          100.0           5.0

                           OCTAVE BAND LEVELS (A)
            63      125     250     500     1000    2000    4000    8000
          50.4     55.7    53.7    65.7     67.5    65.1    58.7    50.1

         LE(A)     L90     L50     L10     SIGMA
          72.1     61.1    68.4    75.7      5.7
RECEIVER              XRC           YRC            ZRC
   4                150.0          100.0           5.0

                           OCTAVE BAND LEVELS (A)
            63      125     250     500     1000    2000    4000    8000
          49.5     54.8    52.9    64.9     67.0    64.5    58.4    49.6

         LE(A)     L90     L50     L10     SIGMA
          71.5     61.0    68.0    75.0      5.5
RECEIVER              XRC           YRC            ZRC
   5                200.0          100.0           5.0

                           OCTAVE BAND LEVELS (A)
            63      125     250     500     1000    2000    4000    8000
          48.8     54.1    52.3    64.4     66.5    64.0    58.2    49.2

         LE(A)     L90     L50     L10     SIGMA
          71.0     60.7    67.6    74.5      5.4
```

FIGURE 7-3. (Continued)

```
SAMPLE PROBLEM 3              (SAI MOD 12/20/76)
ROADWAY     1
NUMBER OF                     VEH/H          MPH
TYPE 1 VEH
    1                         0.1350D 04     0.5000D 02
NUMBER OF                     VEH/H          MPH
TYPE 2 VEH
    1                         0.7500D 02     0.5000D 02
                             SOURCE COORD IN FT
NUMBER       X                Y              Z
    1      0.0                0.6000D 01     0.0
    2      0.1000D 05         0.6000D 01     0.0
ROADWAY     2
NUMBER OF                     VEH/H          MPH
TYPE 1 VEH
    1                         0.1250D 04     0.5000D 02
NUMBER OF                     VEH/H          MPH
TYPE 2 VEH
    1                         0.5000D 02     0.5000D 02
                             SOURCE COORD IN FT
NUMBER       X                Y              Z
    1     -0.1000D 05         0.6000D 01     0.0
    2      0.0                0.6000D 01     0.0
ROADWAY     3
NUMBER OF                     VEH/H          MPH
TYPE 1 VEH
    1                         0.1000D 03     0.4500D 02
NUMBER OF                     VEH/H          MPH
TYPE 2 VEH
    1                         0.2500D 02     0.4500D 02
                             SOURCE COORD IN FT
NUMBER       X                Y              Z
    1     -0.1000D 05         0.5000D 04     0.0
    2      0.0                0.6000D 01     0.0
ROADWAY     4
NUMBER OF                     VEH/H          MPH
TYPE 1 VEH
    1                         0.5000D 03     0.6000D 02
NUMBER OF                     VEH/H          MPH
TYPE 2 VEH
    1                         0.5000D 02     0.6000D 02
                             SOURCE COORD IN FT
NUMBER       X                Y              Z
    1     -0.1000D 05        -0.6000D 01     0.0
    2      0.1000D 05        -0.6000D 01     0.0
BARRIER     1  (A)                BARRIER COORD IN FT
NUMBER       X                Y              Z
    1      0.1000D 03         0.2000D 02     0.6000D 01
    2      0.1000D 05         0.2000D 02     0.6000D 01
RECEIVER                      RECEIVER COORD IN FT
NUMBER       X                Y              Z
    1      0.0                0.1000D 03     0.5000D 01
    2      0.5000D 02         0.1000D 03     0.5000D 01
    3      0.1000D 03         0.1000D 03     0.5000D 01
    4      0.1500D 03         0.1000D 03     0.5000D 01
    5      0.2000D 03         0.1000D 03     0.5000D 01
```

FIGURE 7-3. (Continued)

```
SAMPLE PROBLEM 3                (SAI MOD 12/20/76)
RECEIVER              XRC            YRC            ZRC
   1                  0.0           100.0           5.0

                            OCTAVE BAND LEVELS (A)
              63      125      250      500     1000     2000     4000     8000
             52.1     57.2     65.2     67.2     68.8     66.5     60.0     51.8

          LE(A)       L90      L50      L10      SIGMA
           73.5      63.0     70.0     77.1       5.5
RECEIVER              XRC            YRC            ZRC
   2                  50.0          100.0           5.0

                            OCTAVE BAND LEVELS (A)
              63      125      250      500     1000     2000     4000     8000
             51.4     56.7     54.7     66.7     68.4     66.1     59.6     51.3

          LE(A)       L90      L50      L10      SIGMA
           73.1      62.3     69.5     76.6       5.6
RECEIVER              XRC            YRC            ZRC
   3                 100.0          100.0           5.0

                            OCTAVE BAND LEVELS (A)
              63      125      250      500     1000     2000     4000     8000
             50.5     55.9     53.9     66.0     67.8     65.5     59.2     50.7

          LE(A)       L90      L50      L10      SIGMA
           72.4      61.8     68.9     76.0       5.6
RECEIVER              XRC            YRC            ZRC
   4                 150.0          100.0           5.0

                            OCTAVE BAND LEVELS (A)
              63      125      250      500     1000     2000     4000     8000
             49.6     54.9     53.1     65.2     67.2     64.8     58.8     50.1

          LE(A)       L90      L50      L10      SIGMA
           71.7      61.6     68.4     75.3       5.3
RECEIVER              XRC            YRC            ZRC
   5                 200.0          100.0           5.0

                            OCTAVE BAND LEVELS (A)
              63      125      250      500     1000     2000     4000     8000
             48.9     54.3     52.5     64.6     66.7     64.3     58.4     49.6

          LE(A)       L90      L50      L10      SIGMA
           71.2      61.2     68.0     74.7       5.3
```

FIGURE 7-3. (Continued)

```
SAMPLE PROBLEM 4              (SAI MOD 12/20/76)
ROADWAY     1
NUMBER OF                     VEH/H          MPH
TYPE 1 VEH
   1                          0.1350D 04     0.5000D 02
NUMBER OF                     VEH/H          MPH
TYPE 4 VEH
   1                          0.7500D 02     0.5000D 02
                             SOURCE COORD IN FT
NUMBER        X                 Y              Z
   1       0.0                0.6000D 01     0.0
   2       0.1000D 05         0.6000D 01     0.0
ROADWAY     2
NUMBER OF                     VEH/H          MPH
TYPE 1 VEH
   1                          0.1250D 04     0.5000D 02
NUMBER OF                     VEH/H          MPH
TYPE 4 VEH
   1                          0.5000D 02     0.5000D 02
                             SOURCE COORD IN FT
NUMBER        X                 Y              Z
   1      -0.1000D 05         0.6000D 01     0.0
   2       0.0                0.6000D 01     0.0
ROADWAY     3
NUMBER OF                     VEH/H          MPH
TYPE 1 VEH
   1                          0.1000D 03     0.4500D 02
NUMBER OF                     VEH/H          MPH
TYPE 4 VEH
   1                          0.2500D 02     0.4500D 02
                             SOURCE COORD IN FT
NUMBER        X                 Y              Z
   1      -0.1000D 05         0.5000D 04     0.0
   2       0.0                0.6000D 01     0.0
ROADWAY     4
NUMBER OF                     VEH/H          MPH
TYPE 1 VEH
   1                          0.5000D 03     0.6000D 02
NUMBER OF                     VEH/H          MPH
TYPE 4 VEH
   1                          0.5000D 02     0.6000D 02
                             SOURCE COORD IN FT
NUMBER        X                 Y              Z
   1      -0.1000D 05        -0.6000D 01     0.0
   2       0.1000D 05        -0.6000D 01     0.0
BARRIER     1  (A)                BARRIER COORD IN FT
NUMBER        X                 Y              Z
   1       0.1000D 03         0.2000D 02     0.6000D 01
   2       0.1000D 05         0.2000D 02     0.6000D 01
RECEIVER                      RECEIVER COORD IN FT
NUMBER        X                 Y              Z
   1       0.0                0.1000D 03     0.5000D 01
   2       0.5000D 02         0.1000D 03     0.5000D 01
   3       0.1000D 03         0.1000D 03     0.5000D 01
   4       0.1500D 03         0.1000D 03     0.5000D 01
   5       0.2000D 03         0.1000D 03     0.5000D 01
```

FIGURE 7-3. (Continued)

```
SAMPLE PROBLEM 4                (SAI MOD 12/20/76)
RECEIVER                 XRC          YRC          ZRC
   1                     0.0         100.0         5.0

                          OCTAVE BAND LEVELS (A)
               63       125      250      500     1000     2000     4000     8000
              43.6     52.5     57.3     61.9     64.2     63.6     55.8     47.6

        LE(A)       L90       L50       L10     SIGMA
         68.9      62.6      67.3      72.0      3.7
RECEIVER                 XRC          YRC          ZRC
   2                    50.0         100.0         5.0

                          OCTAVE BAND LEVELS (A)
               63       125      250      500     1000     2000     4000     8000
              43.1     51.9     56.8     61.3     63.6     63.0     55.1     46.9

        LE(A)       L90       L50       L10     SIGMA
         68.2      61.8      66.6      71.4      3.8
RECEIVER                 XRC          YRC          ZRC
   3                   100.0         100.0         5.0

                          OCTAVE BAND LEVELS (A)
               63       125      250      500     1000     2000     4000     8000
              42.2     51.0     55.8     60.2     62.4     61.7     53.8     45.4

        LE(A)       L90       L50       L10     SIGMA
         67.0      60.5      65.4      70.2      3.8
RECEIVER                 XRC          YRC          ZRC
   4                   150.0         100.0         5.0

                          OCTAVE BAND LEVELS (A)
               63       125      250      500     1000     2000     4000     8000
              41.1     49.8     54.5     58.8     60.7     59.8     51.7     43.1

        LE(A)       L90       L50       L10     SIGMA
         65.4      59.6      64.0      68.4      3.4
RECEIVER                 XRC          YRC          ZRC
   5                   200.0         100.0         5.0

                          OCTAVE BAND LEVELS (A)
               63       125      250      500     1000     2000     4000     8000
              40.3     49.0     53.6     57.7     59.3     58.1     49.8     40.6

        LE(A)       L90       L50       L10     SIGMA
         64.0      59.0      62.9      66.8      3.1
```

FIGURE 7-3. (Concluded)

7.4 BEFORE AND AFTER COMPARISONS

This section presents a discussion of the before and after comparisons of sound level estimates for the example problem illustrated in Sections 7.1 through 7.3. Predictions using the MOD-03 version are considered to be the "before" estimates and predictions using the MOD-04 version are considered to the "after" estimates. The reader may refer to pages 33 to 43 of Reference 2 and to Figure 7-3 on page 46 of this manual for the "before" and "after" results, respectively.

First, the differences in sound level estimates between the sample problems will be discussed to illustrate the effect of altering the site configuration. Sample Problem 1 defines the site using a reflecting barrier and an absorptive ground strip modelling a stand of trees. Sample Problem 2 is identical to Problem 1 except that the barrier is absorptive. For both the MOD-03 version and the MOD-04 version of the prediction code, the sound level estimates for Sample Problem 2 are less than that predicted for Sample Problem 1 indicating that ignoring reflections has decreased the predicted levels. This result is expected. For both versions of the prediction code and all receivers the decrease in predicted sound level between Sample Problems 1 and 2 is from 1.5 dB for receiver 1 to 1.1 dB for receiver 5 (See Figure 7-1). This observation applies equally to the energy mean sound level, LEA, and the L10 level predictions. Sample Problem 3 differs from Sample Problem 2 in that the absorptive ground strip modelling the stand of trees is ignored. For both the MOD-03 version and MOD-04 version of the prediciton code, the predicted values of LEA and L10 increase from 0.7 dB for receiver 1 to 0.2 dB for receiver 2 (See Figure 7-1) as a result of deleting the absorptive ground strip.

Sample Problem 4 differs from Sample Problem 3 in that the code-defined Type 2 vehicle (heavy trucks) is replaced by a user defined "new" vehicle. For the sound level estimates using the MOD-03 version and the MOD-04 version of the prediction code noise emission characteristics of the "new" or user-defined vehicle type were identical. Introduction of the "new" vehicle to replace the code-defined Type 2 (heavy truck) vehicle

reduced the sound level estimates at all receivers for both versions of the prediction code. For the MOD-03 version, both the LEA and L10 predictions decreased from 6.0 dB at receiver 1 to 7.6 dB at receiver 5. For the MOD-04 predictions, the decrease in LEA values was from 3.6 dB at receiver 1 to 7.2 dB at receiver 5 and the decrease in L10 values was from 5.1 dB at receiver 1 to 6.9 dB at receiver 5. The differences in these estimates are indicative of the differences in the vehicle noise emission characteristics for heavy trucks for the MOD-03 version and the MOD-04 version of the prediction code. The above discussion indicates that for changes only in the site geometric and/or acoustic characteristics the MOD-03 version and the MOD-04 version of the prediction code estimate identical changes in sound level. The following discussion focuses upon the emission characteristics of the vehicles and the differences in sound level estimates for the MOD-03 version and the MOD-04 version of the prediction code.

Since the differences in site configuration are essentially similar for the MOD-03 version and the MOD-04 version of the prediction code, the differences between the sound level estimates for Sample Problem 1 and Sample Problem 4 will be discussed.

For Sample Problem 1, the MOD-04 version of the prediction code estimates values of the energy mean sound level descriptor 1.1 dB below the estimate using the MOD-03 version for receivers 1 and 2. For receivers 3, 4, and 5 the differences are 0.9, 0.6, and 0.4 dB, respectively, with the MOD-04 version being lower. Differences in the predicted L10 values are similar.

For Sample Problem 4, the MOD-04 version predicts results identical to the MOD-03 version since the user-defined vehicle was identical in both cases.

The differences in sound level predictions described above are not dramatic. This lack of drama is a result of the example problem rather than a complete utilization of the capabilities of the MOD-04 version of the prediction code. Figure 7-4 is reproduced from

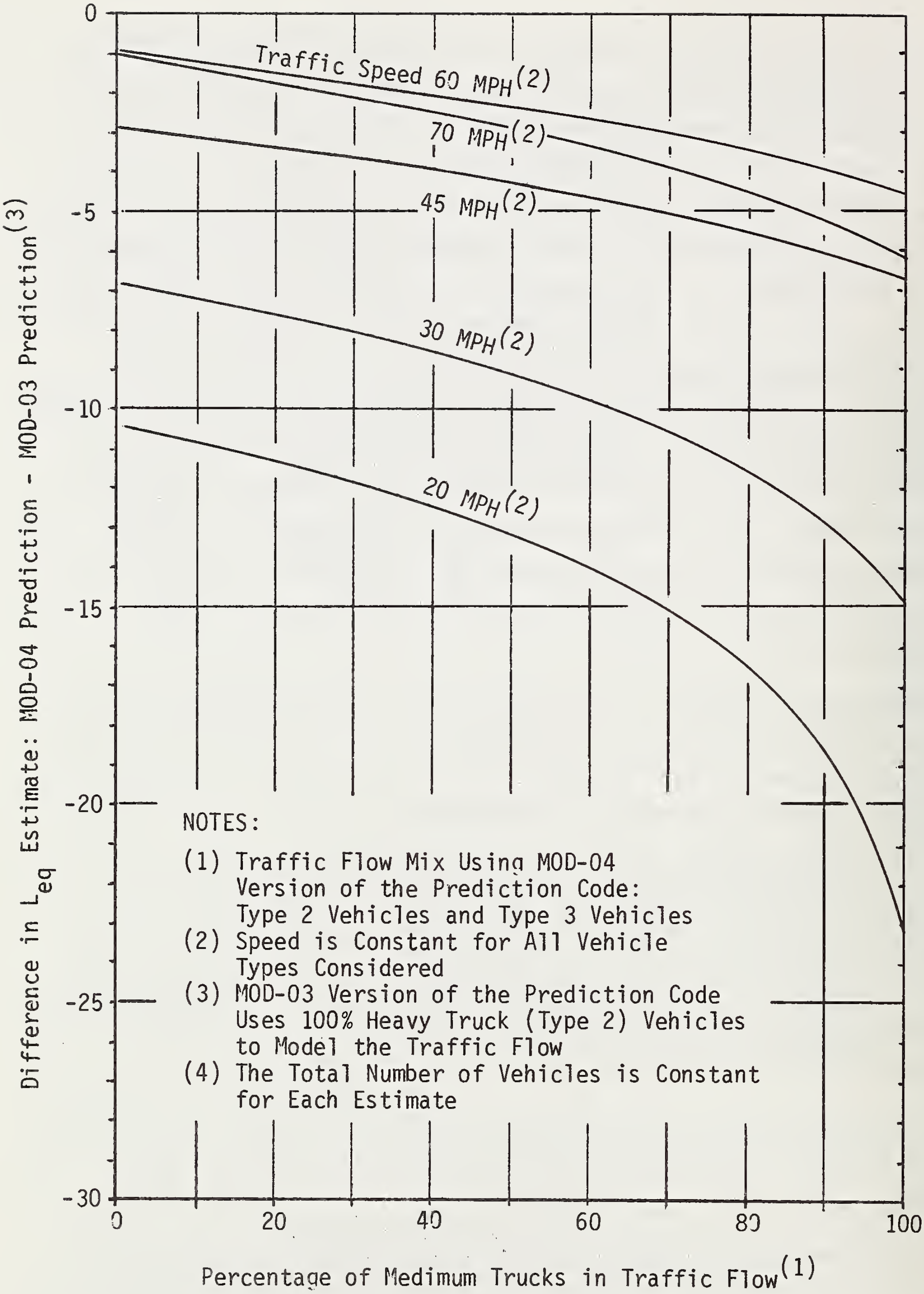


FIGURE 7-4. DIFFERENCE IN PREDICTED L_{eq} ESTIMATE BETWEEN MOD-03 AND MOD-04 VERSIONS OF THE TSC PREDICTION CODE

Reference 8 and illustrates the extreme differences in sound level estimates that could arise if one compares MOD-03 results with MOD-04 results.

Figure 7-4 presents the difference in level (LEA) as predicted by the MOD-04 version and the MOD-03 version as related to traffic flow speed and percentage mix of medium trucks to heavy trucks. The comparison is for a single roadway carring a constant number of vehicles at a constant speed. The vertical axis is the level difference with negative values indicating that the MOD-04 predictions are less than the MOD-03 predictions. The horizontal axis is the percentage of medium trucks in the traffic flow. The curves of constant traffic flow speed cover the range of 20 mph to 70 mph. For the MOD-03 prediction, the traffic flow was modeled using heavy trucks (code-defined as Type 2 vehicles) so that the sound level estimate is independent of speed. For the MOD-04 predictions, the traffic flow was modeled using both heavy trucks and medium trucks (code-defined as Type 2 and Type 3 vehicles, respectively). From Figure 7-4, it is seen that for 0% medium trucks and a traffic flow speed of 60 mph the level difference between the MOD-04 version and the MOD-03 version of the prediction code is slightly greater than 1 dB. This is the same difference as predicted for Sample Problem 1 of the example problem of Section 7.3. Hence, Figure 7-4 indicates rather dramatic decreases in sound level estimates using the MOD-04 version of the prediction code if the traffic flow comprises a significant mix of medium trucks to heavy trucks and if the traffic flow speed is less than approximately 45 mph (See Figure A-2, page A-14 of Appendix A).

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APPENDIX A

BASIC FORMULATION OF COMPUTERIZED PREDICTION MODEL — ACOUSTICS

This Appendix presents the basic formulation for the acoustic models utilized by the highway traffic noise prediction scheme. Both the basic derivation for the model and the algorithm coded in the program are presented.

A.1 ENERGY MEAN LEVEL

Consider the sound emanating from a single vehicle located at a point x on a straight road segment extending from x_1 to x_2 as indicated in Figure A-1. The acoustic intensity, I, at a receiver located at a distance, d, from the road segment is given as:

$$I = I_o\, r_o^2\, 10^{-D/10}/(x^2 + d^2) \qquad \text{(A-1)}$$

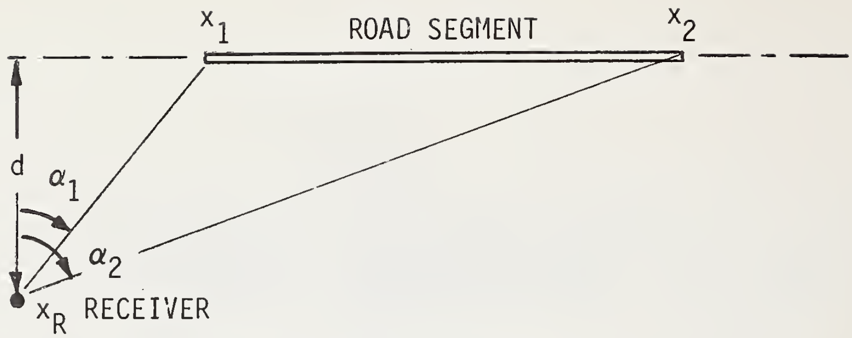
where I_o is a reference intensity at a distance r_o from the road segment

r_o is a reference distance (specified in the coded algorithm as 50 feet)

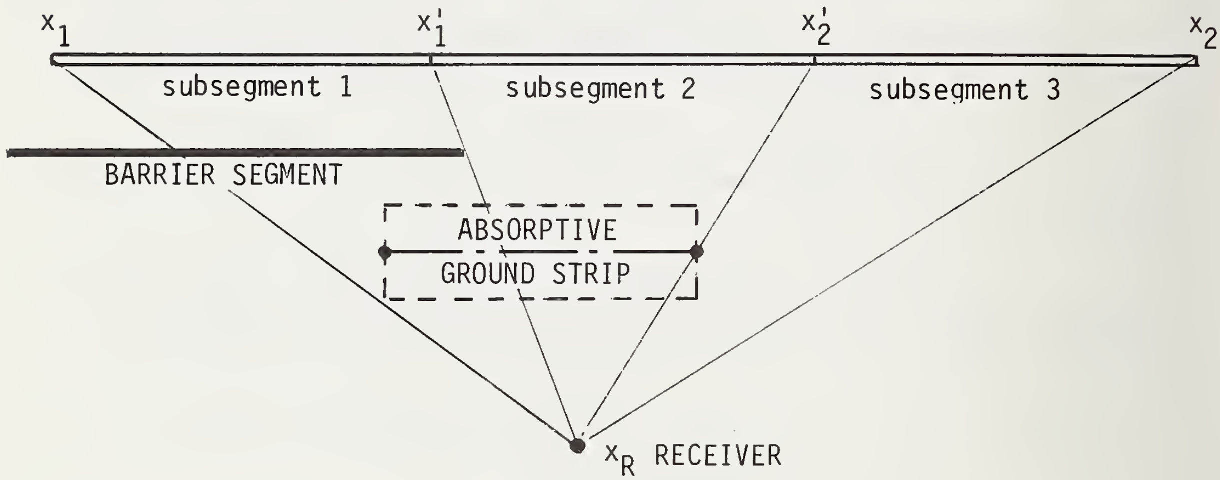
D is a distance attenuation factor for acoustic propagation, dB.

The relationship indicated in Equation (A-1) assumes a point source that is nondirectional so that the intensity of the sound field decreases with the inverse square of the distance from the source to the receiver. The reference intensity, I_o, is defined for hemispherical radiation corresponding to a point source on a reflective plane.

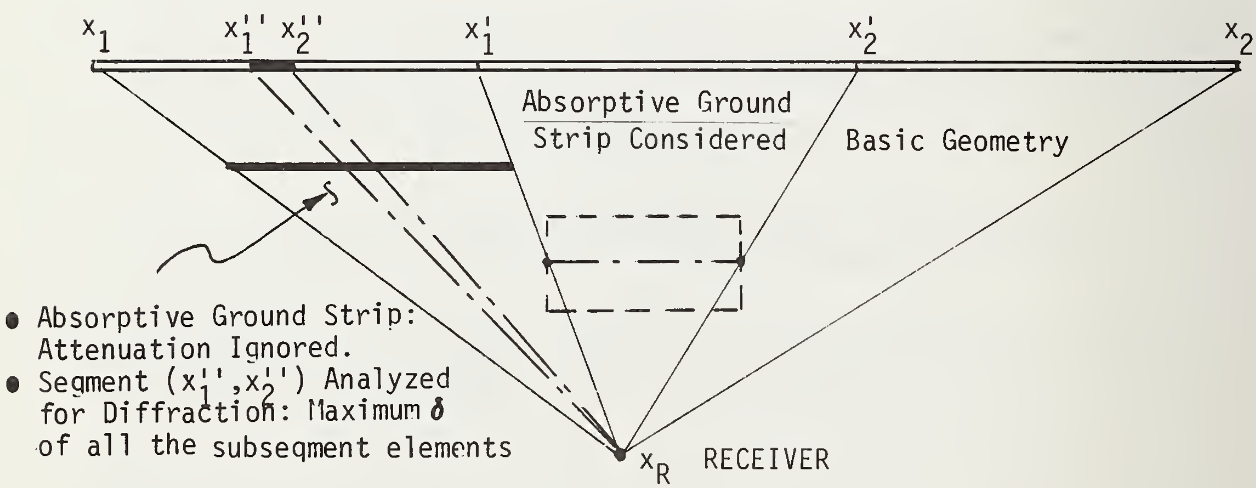
For a uniform flow of vehicles, each exhibiting identical noise characteristics and each traveling at the same speed, the



(a) Basic Roadway/Receiver Geometry



(b) Subdivision of Roadway Segments into Elements



(c) Computer View of Roadway/Receiver Geometry

FIGURE A-1. BASIC SOURCE/RECEIVER GEOMETRY

vehicle flow is defined in terms of a vehicle concentration, λ (vehicles per foot), and the mean acoustic intensity at the receiver is given as:

$$I = I_o \, r_o^{\,2} \int_{x_1}^{x_2} \frac{\lambda \, 10^{-D/10} \, dx}{(x^2 + d^2)} \qquad \text{(A-2)}$$

which is the incoherent line source model for the vehicle type under consideration.

It is now assumed that both the distance attenuation term, $10^{-D/10}$, and the vehicle concentration, λ, are independent of location on the roadway segment. That is, both the distance attenuation, D, and the vehicle concentration, λ, are assumed to be constant for the road segment. Performing the resulting integration, the sound intensity at the receiver due to the flow of identical vehicles on the roadway segment is:

$$I = I_o \, r_o^{\,2} \, (\lambda/d) \, \Delta\alpha \, 10^{-D/10} \qquad \text{(A-3)}$$

where
$$\Delta\alpha = |\alpha_2 - \alpha_1|$$
$$\alpha_i = \mathrm{TAN}^{-1} \, (x_i/d)$$

The mean vehicle concentration, λ, expressed in terms of vehicles per unit length of roadway, is defined in terms of the traffic volume, Q, of the roadway in units of vehicles per unit time and the average vehicle speed, V, in units of length per unit time. For "worst hour" prediction of highway traffic noise, Q is taken as the vehicle flow rate expressed as vehicles per hour and V is taken as the vehicle speed expressed as miles per hour. Hence, the mean vehicle concentration, λ, is expressed as

$$\lambda = Q/(5280 \cdot V), \text{ vehicles/ft} \qquad \text{(A-4)}$$

where Q is the traffic volume of the roadway in vehicles per hour

V is the vehicle speed (corresponding to Q) in miles per hour.

The factor 5280 in the denominator of Equation (A-4) is the conversion factor from statute miles to feet.

To simulate the flow of mixed traffic conditions on a road segment-receiver geometry, as indicated in Figure A-1, the total acoustic intensity at the receiver is simply the summation of the acoustic intensities for each vehicle type comprising the mixed traffic flow (this is a combination of the incoherent line source model for several different vehicle types). Assuming that the mixed traffic flow comprises N distinct vehicle types described by an average reference acoustic intensity, $\tilde{I}_{o,n}$, and a mean vehicle concentration, $\lambda_n = Q_n/V_n$, the total acoustic intensity at the receiver is

$$I = \left(\frac{r_o^2}{d} \Delta\alpha\right) \sum_{n=1}^{N} \lambda_n \tilde{I}_{o,n} 10^{-D_n/10} \tag{A-5}$$

where it has been assumed that all reference intensities, $\tilde{I}_{o,n}$, correspond to a reference distance, r_o, that is the same for each vehicle type. The coefficient on Equation (A-5) is a grouping of parameters associated only with the roadway segment-receiver geometry.

The average reference intensity, $\tilde{I}_{o,n}$, associated with a vehicle type is related to an average reference sound level, $\tilde{L}_{o,n}$, for the vehicle type by the expression:

$$\tilde{I}_{o,n} = 10^{\tilde{L}_{o,n}/10} \tag{A-6}$$

Field measurements (see Section A.2 and Subroutine INTER) have shown that for a category of vehicles (heavy trucks, for example) values of the

reference sound level exhibit a normal probability distribution for vehicles traveling at similar speeds. That is, for a given speed, all vehicles of the same type can be represented as noise sources defined by a mean reference sound level, $\overline{L}_{o,n}$, and a reference standard deviation, $\sigma_{o,n}$. In order to express $\tilde{L}_{o,n}$ in terms of $\overline{L}_{o,n}$ and $\sigma_{o,n}$, one performs the following integration (assuming a normal distribution of sound levels):

$$\tilde{I}_{o,n} = 10^{\tilde{L}_{o,n}/10} = \frac{1}{\sqrt{2\pi}\,\sigma_{o,n}} \int_{-\infty}^{\infty} 10^{L/10} \, X$$

$$e^{-1/2(L-\overline{L}_{o,n})^2/\sigma_{o,n}^2} \, dL \tag{A-7}$$

$$\tilde{I}_{o,n} = 10^{\tilde{L}_{o,n}/10} = 10^{\overline{L}_{o,n}/10} \, e^{1/2(\sigma_{o,n}/4.35)^2} \tag{A-8}$$

$$4.35 \approx 10/\ln(10) \qquad \ln(x) = \log_e(x)$$

Considering that there may be R different roadway segments contributing to the acoustic intensity at the receiver, it is necessary to sum the contribution of each roadway segment using the result of Equation (A-5). Substituting from Equation (A-8) into Equation (A-5) and summing over R roadway segments, the expression for the mean acoustic intensity at a receiver for complex traffic flows on several roadway segments is:

$$I = r_o^2 \sum_{j=1}^{R} \left(\frac{\Delta\alpha}{d}\right)_j \sum_{n=1}^{N} \lambda_n \, 10^{-D_{jn}/10} \, 10^{\overline{L}_{o,nj}/10} \, X$$

$$e^{1/2(\sigma_{o,nj}/4.35)^2} \tag{A-9}$$

where the index j denotes a roadway segment and the index n denotes the vehicle type.

The mean (or equivalent) sound level at the receiver is then expressed as

$$L_e = 10 \log (I), \text{ dB} \qquad \log(x) = \log_{10}(x) \qquad \text{(A-10)}$$

It is emphasized now that the result given by Equation (A-9) corresponds to either a frequency band of noise or a frequency-weighted noise depending upon the definition of $I_{o,nj}$ and $\sigma_{o,nj}$, as may be appropriate. The attenuation factor

$$10^{-D_{jn}/10}$$

has been indicated as a possible vehicle-dependent factor since the attenuation may depend upon vehicle source height when considering sound propagation over barriers or topography.

The results presented in Equations (A-9) and (A-10) are the basic analytical formulation of the highway traffic noise prediction model. These results are, however, coded in a slightly different form for actual calculations. The following discussion relates to the coded model.

First, the basic unit analyzed by the prediction code is a roadway segment-receiver geometry illustrated in Figure A-1 corresponding to each term in the summation over the index, j, in Equation (A-9) for each receiver. The sound intensity at a receiver for each roadway segment and intervening barriers, ground strips, and topography is calculated in subroutine GEOMRY using a normalized acoustic intensity. The acoustic intensity is normalized to the reference distance, r_o, as follows (See equation (A-12b)):

$$r_o^2 = (50)^2 = (100/2)^2 = 10^4/4 = 10^4 \cdot 10^{-6/10}$$

$$= 10^{10} \cdot 10^{-66/10}$$

This manipulation is persented to clarify the following result.

Then, Equation (A-9) becomes

$$I = 10^{10} \sum_{j=1}^{R} I_j^* \tag{A-11a}$$

$$I_j^* = (\Delta\alpha/d)_j \sum_{n=1}^{N} \lambda_n \, 10^{-D_{jn}/10} \, 10^{(\overline{L}_{o,jn} - 66)/10} \times$$

$$e^{1/2(\sigma_{o,jn}/4.35)^2} \tag{A-11b}$$

Equation (A-10) is then expressed as

$$L_e = 10 \log (I) = 10 \log \left(10^{10} \sum_{j=1}^{R} I_j^*\right) \tag{A-12a}$$

$$L_e = 100 + 10 \log \left(\sum_{j=1}^{R} I_j^*\right) \tag{A-12b}$$

Hence, the reference distance r_o = 50 feet is coded as a $10^{-66/10}$ term that appears in subroutine GEOMRY and a 100 dB term that appears in the MAIN Program. This emphasis is presented so that if other values of the reference distance are desired, the reader can easily identify the required segments of code. If the reference distance is altered, however, one must appropriately alter the reference sound level, $\overline{L}_{o,jn}$, and the reference standard deviation, $\sigma_{o,jn}$, to correspond to the new reference distance.

As a final note, the reader should remember that the calculations defined by Equations (A-9) and (A-10) or (A-11) and (A-12) are required for each receiver and each frequency band. The reference sound levels, $\overline{L}_{o,jn}$, and the reference standard deviations, $\sigma_{o,jn}$, are

both described as functions of vehicle type, vehicle speed, and octave-band center frequency.

A.2 VEHICLE REFERENCE LEVELS

The basic parameters affecting traffic noise estimates using the model described in Section A.1 are then the parameters:

$\bar{L}_{o,jn}$ — The mean reference sound level for the n^{th} vehicle type at a distance r_o = 50 feet from the j^{th} roadway segment

$\sigma_{o,jn}$ — The standard deviation of the mean reference levels for the n^{th} vehicle type at a distance r_o = 50 feet from the j^{th} roadway segment.

Both $\bar{L}_{o,jn}$ and $\sigma_{o,jn}$ are independent of the roadway segment; however, consideration of the roadway segment is emphasized to illustrate how the prediction code combines these basic parameters for mixed traffic flow conditions at receivers affected by several road segments.

The specific values for $\bar{L}_{o,jn}$ and $\sigma_{o,jn}$ are described as functions of vehicle speed and frequency in the prediction code for each vehicle type. The prediction code defines four (4) vehicle types as follows:

Type 1 Vehicle (Automobiles and Light Trucks):

All vehicles with two axles and four wheels designed primarily for transportation of nine or fewer passengers (automobiles) or for transportation of cargo (light trucks). Generally, the gross vehicle weight is less than 10,000 pounds.

Type 2 Vehicle (Heavy Truck):

All vehicles having three or more axles and designed for the transportation of cargo. Generally, the gross vehicle weight is greater than 26,000 pounds.

Type 3 Vehicle (Medium Truck):

All vehicles having two axles and six wheels designed for the transportation of cargo. Generally, the gross vehicle weight is greater than 10,000 pounds but less than 26,000 pounds.

Type 4 Vehicle (User Defined):

The noise emission characteristics of the Type 4 vehicle are defined by the user to include an additional vehicle type not appropriate to the Type 1, Type 2, or Type 3 vehicles defined above (see Section 6 and Appendix E: Subroutine INPUT).

Consideration of effects of vehicle engine type, operation of cooling fans, tire noise, etc., for a specific vehicle type is implicitly defined by the reference values of $\overline{L}_{o,jn}$ and $\sigma_{o,jn}$, stored in the prediction code and any user-defined vehicle emissions should consider this fact. The reference values for the Type 2 and Type 3 vehicles were obtained by measuring vehicle pass-by sound levels and calculating $\overline{L}_{o,n}$ as the average value of the peak pass-by sound level for a vehicle type and $\sigma_{o,n}$ as the standard deviation of the peak pass-by sound levels for the vehicle type for vehicle speeds between 20 miles per hour and 70 miles per hour (see Reference A-1).

The reference values for the Type 1 vehicles (automobiles and light trucks) were obtained using the data in Reference A-2 reformulated to provide a more convenient computation for the code (see Appendix E: Subroutine INTER).

For the Type 1 vehicles, the speed dependence of sound level for a given frequency band is expressed as:

$$\overline{L}_{0,1} = C_{01} + C_{11} \log (V) \qquad \text{(A-13a)}$$

$$\log(x) = \log_{10}(x)$$

and of the standard deviation is expressed as

$$\sigma_{0,1} = S_{01} \tag{A-13b}$$

The speed dependence defined by Equations (A-13) is numerically identical to that utilized by previous versions of the TSC noise prediction code for Type 1 vehicles (automobiles and light trucks).

For Type 2 and Type 3 vehicles (heavy and medium trucks, respectively), the speed dependence of the sound level and the standard deviation is expressed, for a given frequency band, as:

$$\overline{L}_{o,n} = C_{0n} + C_{1n}V + C_{2n}\,V^2 \tag{A-14a}$$

$$\sigma_{o,n} = S_{0n} + S_{1n}V + S_{2n}\,V^2 \tag{A-14b}$$

$$n = 2,\ 3 \text{ (Vehicle Type)}$$

For the user-defined Type 4 vehicle, the present version of the code describes the vehicle reference levels as presented in Equation (A-14). However, the input data requirements presently allow the user the option of specifying only the coefficients C_{04} and S_{04} as functions of frequency with the coefficients C_{14}, C_{24}, S_{14}, and S_{24} set equal to zero (i.e., there is no speed dependence for Type 4 vehicle reference levels). The descriptions of subroutines INPUT and INTER presented in Appendix E illustrate how a user may input these coefficients (to include Type 4 vehicle speed dependence) in the present version of the prediction code by simply redefining a constant (one card). However, the user must understand that definitions of these constants imply a rather extensive experimental data base and data reduction procedure if speed dependence of noise predictions is required for the Type 4 vehicle.

For reference, the coefficients in Equations (A-13) and (A-14) that are stored in the prediction code are presented in Tables A-1 and A-2 for the vehicle emission reference levels and the reference values for the standard deviation, respectively. Figure A-2 presents a comparison of the overall A-weighted vehicle emission levels versus vehicle speed for the data used by this prediction code and the levels previously specified by the TSC noise prediction code.

Finally, the reference values for $\overline{L}_{o,n}$ and $\sigma_{o,n}$ are defined for vehicle speed ranges between 20 miles per hour and 70 miles per hour only. If the user defines a vehicle speed less than 20 miles per hour, the prediction code uses reference levels at 20 miles per hour. If the user defines a vehicle speed greater than 70 miles per hour, the prediction code uses reference levels at 70 miles per hour. The reference levels specified by the prediction procedure are the A-weighted overall sound level and the A-weighted octave band levels for the eight octave band center frequencies from 63 Hz to 8000 Hz.

A.3 SPECTRAL CALCULATIONS

The highway traffic noise prediction code allows the user to calculate A-weighted overall levels and A-weighted octave band levels for the octave band center frequencies 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz. To allow calculations for these different frequency bands the following algorithm is used to calculate the octave band center frequencies

$$f_n = 2^n \cdot 10^3/64 \qquad \text{(A-15)}$$

$$n = 2, 3, \ldots, 9$$

The algorithm presented in Equation (A-15) is also used to derive algorithms for calculating barrier diffraction (Subroutine BARFAC), ground attenuation (Subroutine GEOMRY) and atmospheric absorption (Subroutine GEOMRY).

TABLE A-1
COEFFICIENTS FOR VEHICLE REFERENCE
SOUND LEVEL INTERPOLATION POLYNOMIALS

FREQ. Hz	IF	XLREF1 FOR IQ = 1 (AUTOMOBILES)			XLREF FOR IO = 2 (HEAVY TRUCKS: FOUR STATE)			XLREF FOR IQ = 3 (MEDIUM TRUCKS: FOUR STATE)		
		CO(1,IF)	C1(1,IF)	C2(1,IF)	CO(2,IF)	C1(2,IF)	C2(2,IF)	CO(3,IF)	C1(3,IF)	C2(3,IF)
OAL	1	4.80	38.05	0.00	60.637	0.8254	-0.00657	42.690	1.321	-0.0109
63	2	-2.14	27.18	0.00	47.983	0.7786	-0.00948	45.075	0.4574	-0.00407
125	3	-3.17	32.61	0.00	56.170	0.4660	-0.00400	49.971	0.6837	-0.00679
250	4	-13.21	40.76	0.00	38.488	1.4491	-0.01340	42.650	1.1120	-0.0100
500	5	10.84	29.89	0.00	49.917	0.9669	-0.00764	29.336	1.5483	-0.0127
1000	6	9.83	32.61	0.00	53.646	0.8851	-0.00686	22.981	1.8671	-0.0159
2000	7	-18.26	48.92	0.00	62.356	0.4471	-0.00286	18.863	1.9331	-0.0164
4000	8	-7.20	38.05	0.00	60.4879	0.3546	-0.00243	32.410	1.1546	-0.00893
8000	9	-18.21	40.76	0.00	42.855	0.7760	-0.0070	38.208	0.7091	-0.00536

TABLE A-2
COEFFICIENTS FOR VEHICLE REFERENCE STANDARD
DEVIATION INTERPOLATION POLYNOMIALS

FREQ. Hz	IF	SIGL1 FOR IQ = 1 (AUTOMOBILES)			SIGL1 FOR IQ = 2 (HEAVY TRUCKS: FOUR STATE)			SIGL1 FOR IQ = 3 (MEDIUM TRUCKS: FOUR STATE)		
		S0(1,IF)	S1(1,IF)	S2(1,IF)	S0(2,IF)	S1(2,IF)	S2(2,IF)	S0(3,IF)	S1(3,IF)	S2(3,IF)
OAL	1	2.5	0.00	0.00	9.0293	-0.2151	0.00186	-3.3165	0.3077	-0.00329
63	2	2.5	0.00	0.00	-0.3846	0.3206	-0.00393	3.9004	0.0686	-0.000929
125	3	2.5	0.00	0.00	5.8529	-0.0694	0.000571	7.6146	-0.0546	-0.0000714
250	4	2.5	0.00	0.00	0.1839	0.2023	-0.00221	-3.8543	0.4311	-0.00486
500	5	2.5	0.00	0.00	2.9979	0.0426	-0.000429	-6.6989	0.4677	-0.00479
1000	6	2.5	0.00	0.00	10.8732	-0.2269	0.00164	-7.3718	0.5171	-0.00536
2000	7	2.5	0.00	0.00	10.8700	-0.2520	0.0020	-10.3568	0.6231	-0.00636
4000	8	2.5	0.00	0.00	14.3864	-03817	0.00329	-0.3814	0.2077	-0.00229
8000	9	2.5	0.00	0.00	5.1886	-0.00429	-0.000286	-0.7321	0.2226	-0.00243

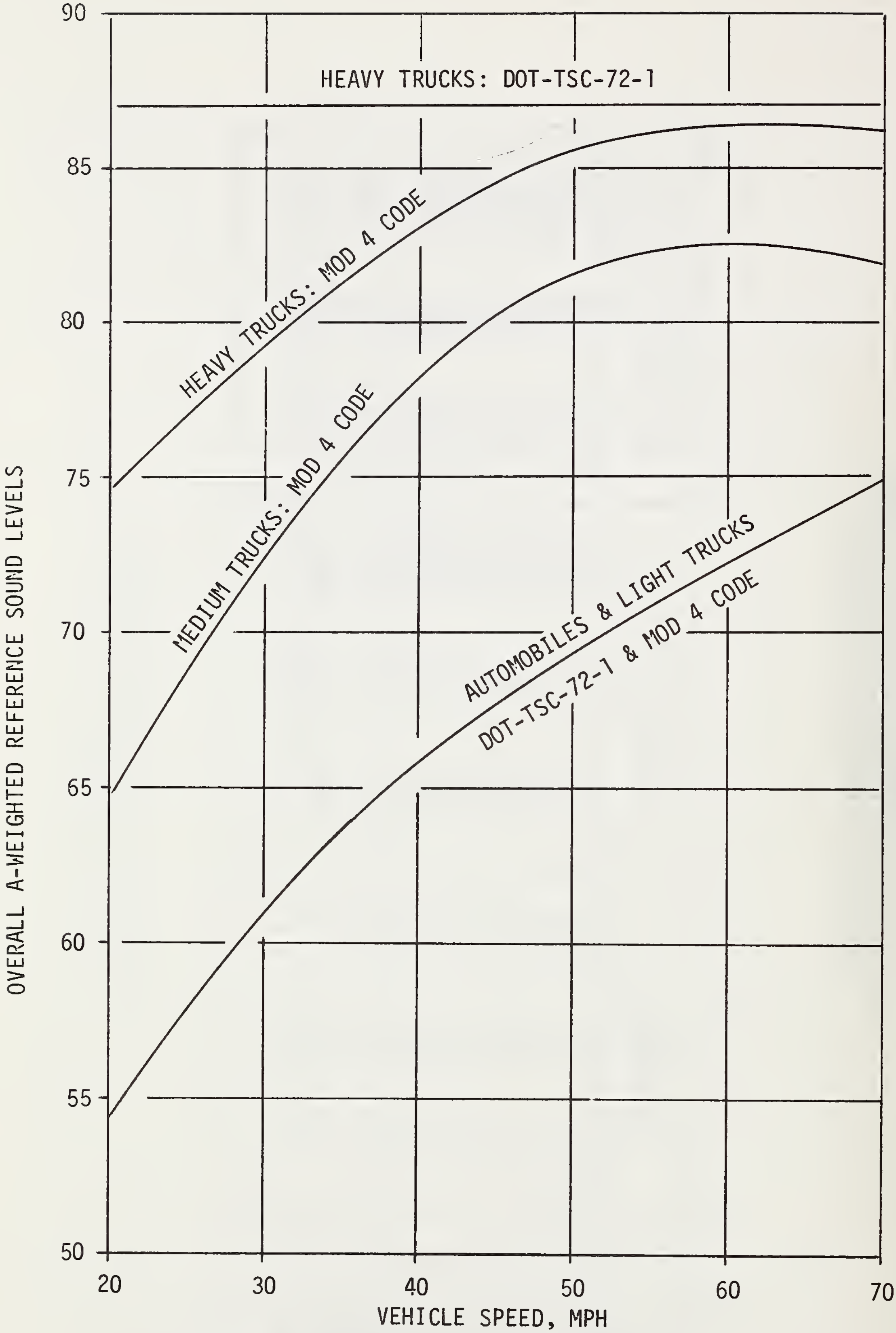


FIGURE A-2. REFERENCE VEHICLE SOUND LEVELS, dBA, VERSUS VEHICLE SPEED

The prediction code specifies a frequency band using an integer index IF that can be assigned values from IF = 1 to IF = NF (NF equal to or less than 9 as specified by the user -- see Subroutine INPUT). For IF = 1, the overall A-weighted sound level is calculated with barrier attenuation, ground absorption, and atmospheric absorption being calculated at 500 Hz (IF = 5). The code then calculates the sound level estimate, sequentially, for values of IF = 2,. . . , NF as specified by the user. All spectral calcualtions are independent (i.e., each problem is handled separately by the code). If the user specifies NF = 9 (i.e., the code calculates all octave band center frequencies at each receiver) the prediction code prints the value of "LE(A)" that is the intensity summation of the octave band levels. However, if the user specifies NF to be less than 9, the code prints the independently calculated value for "LE(A)". Slight differences will be observed for the values of "LE(A)" as a result of the consideration of source-receiver attenuation affects that are frequency dependent. These slight differences should be of no concern to the user (the two estimates are generally within 1dB of each other). It is recommended that if the user is interested in obtaining octave band levels, he should specify NF = 9. Otherwise, the user should specify NF = 1. The user should never associate prediction code accuracy with the specification of the parameter NF since each octave band calculation is independent.

A.4 ATTENUATION OF SOUND LEVELS

The traffic noise prediction code provides for the consideration of the attenuation of sound levels from the source to the receiver due to the following physical factors:

- Distance between source and receiver
- Barriers between source and receiver
- Trees and shrubbery between source and receiver
- Atmospheric absorption
- Reflection of sound to the receiver (negative attenuation).

The basic attenuation included in the acoustic model is an inverse square law spreading of sound intensity (i.e., 3 dB per distance doubling) that is frequency independent. All other forms of excess attenuation considered by the prediction code consider both frequency and distance effects in calculating attenuation as may be appropriate to the models utilized.

By plotting the predicted values of equivalent sound level, LE(A), and the statistical levels (L_{90}, L_{50}, and L_{10}) versus distance, the user will note slight differences in distance attenuation rates for the different descriptors. The reason for this is that both sound level and the composite value of standard deviation decrease with distance at different rates (see Equations (A-5) and (A-35)).

The statistical sound level descriptors are functions of both the equivalent sound level and the standard deviation of the sound level — hence, one would expect to observe differences.

A.5 ATMOSPHERIC ABSORPTION

The traffic noise prediction code utilizes an empirical formula for the attenuation of sound resulting from atmospheric absorption. This formula is dependent upon frequency and distance between the source and the receiver and is specialized for ambient temperatures around 68°F and relative humidity in the range of 50 to 70 percent (A-3).

The empirical formula utilized is

$$D_A = 5.4 \cdot 10^{-4} (2.35)^{(n-5)} r \quad \text{dB} \qquad \text{(A-16)}$$

where n is the octave band frequency index (see Equation (A-15))

r is the source-receiver distance in feet

Attenuation of sound for atmospheric absorption is accomplished in Subroutine GEOMRY. For the overall A-weighted sound level prediction, the value used is that for 500 Hz (i.e., n = 5 in Equation (A-16)).

The distance used by the prediction code in calculating atmospheric absorption is the distance from the receiver to the nearest point on the roadway segment or sub-segment being analyzed. (See discussion following Equation (A-2).)

A.6 DIFFRACTION

Diffraction of sound is caused by obstacles in the direct or reflected propagation paths from the roadway to the receiver. Such obstacles can be artificial barriers, earth berms, hills, buildings, etc. For the calculation of attenuation by diffraction, the obstacle can be modeled by a rigid, impervious screen oriented perpendicular to the ground plane so that sound is diffracted over the top edge of the screen exclusively. The shape of hills and the thickness of barriers are neglected because of the lack of available knowledge. The sound absorption and transmission properties of barriers are not considered because they play a minor role in most practical cases. The neglect of diffraction around the ends of barriers will introduce no significant errors, and it simplifies considerably the computational procedures. Furthermore, a diffracting barrier is then completely specified by the coordinates of the two end points of the top line defining the barrier segment.

The attenuation of sound by barriers is determined primarily by the difference, δ, between the path length of the shortest ray from the source over the top edge of the barrier to the receiver and the path length of the direct ray from the source to the receiver in the absence of the barrier (Figure A-3).

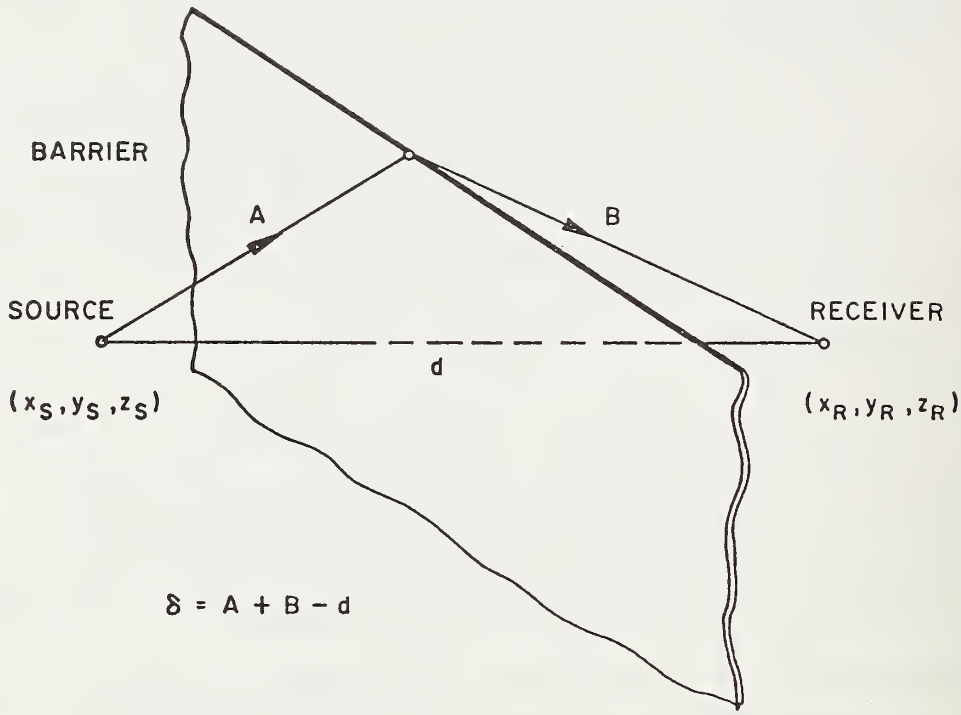


Figure A-3. DEFINITION OF THE PATH LENGTH DIFFERENCE δ FOR SOUND DIFFRACTION BY A BARRIER

For large path length differences, the attenuation in the acoustical shadow zone of a barrier is limited by effects of refraction and scattering of sound in the atmosphere. Based on data (A-4), the coded procedures have a maximum attenuation of 20 dB.

The attenuation for a barrier is not zero for zero path length difference (i.e., for a ray grazing over the barrier). For this situation, the theory of Fresnel diffraction yields an attenuation of about 5 dB. The attenuation becomes negligible when a direct sound ray traveling from the source to the receiver passes far over the top edge of the barrier. To simplify computations, diffraction effects are no longer considered when the height difference

between the direct ray and the top of the barrier is greater than 20 feet.

For height differences of 20 feet or less, the Fresnel number is expressed as:

$$N = \frac{2\delta}{\lambda}, \tag{A-17}$$

where δ is the path length difference and λ is the wavelength corresponding to the center frequency of an octave band. For normal atmospheric conditions, the speed of sound in air is assumed to be 1120 ft/sec. Thus, for a center frequency f, the Fresnel number becomes:

$$N = \frac{2f}{c}\,\delta = f\delta/560 \tag{A-18}$$

The barrier attenuation is calculated as a function of the Fresnel number, using an analytic approximation to the measured data of Maekawa (A-5):

$$D_B = 20 \cdot \log_{10}\left(\frac{\sqrt{2\pi N}}{\tanh \sqrt{2\pi N}}\right) + 5, \text{ dB for } N \geq -0.2 \tag{A-19}$$

$$D_B = 0 \qquad \text{otherwise}$$

Equation(A-19)is applicable to both positive and negative values of N. However, for the actual computation, the values of attenuation are calculated as a function of N using the following relationships (see Subroutine BARFAC):

$$
\begin{aligned}
D_B &= 0 && \text{dB for } N \leq -0.2 \\
D_B &= 20 \cdot \log_{10}\left(\frac{\sqrt{2\pi|N|}}{\tan \sqrt{2\pi|N|}}\right) + 5 && \text{dB for } -0.2 < N \leq 0 \\
D_B &= 20 \cdot \log_{10}\left(\frac{\sqrt{2\pi N}}{\tanh \sqrt{2\pi N}}\right) + 5 && \text{dB for } 0 < N \leq 5.03 \\
D_B &= 20 && \text{dB for } N > 5.03
\end{aligned}
\qquad \text{(A-20)}
$$

The last line in Equation (A-20) accounts for the above-mentioned upper limit to barrier attenuation.

As shown in Figure A-4, the attenuation of the A-weighted sound pressure level of typical passenger car noise is almost identical with the sound attenuation in the 500 Hz band. Hence, the primary number important for the attenuation of road traffic noise is the path length difference, δ.

The path length difference accounts for heights and distances of a point source, a receiver, and the top edge of a barrier. Furthermore, it accounts for the reduced attenuation of rays oblique to the top edge of the barrier (A-6).

For noise from a road segment and for a barrier at oblique angle to the road, the coded procedures find the path length difference δ_N for sound from the nearest point on the road segment affected by the barrier. Then, by assuming a monotonic variation of the path length difference from other points on the road, the extreme ends of the road segment are considered. If the path length differences, δ_1 and δ_2, for these end points differ from δ_N by more than a number that results in an attenuation difference of about 1 dB, the road segment between the near point N and the point 1 or the point 2, respectively, is cut in half. New path length differences are calculated for the new end points of the road segment, and the procedure of reducing the length of the road segment is repeated until the attenuation by diffraction is approximately constant.

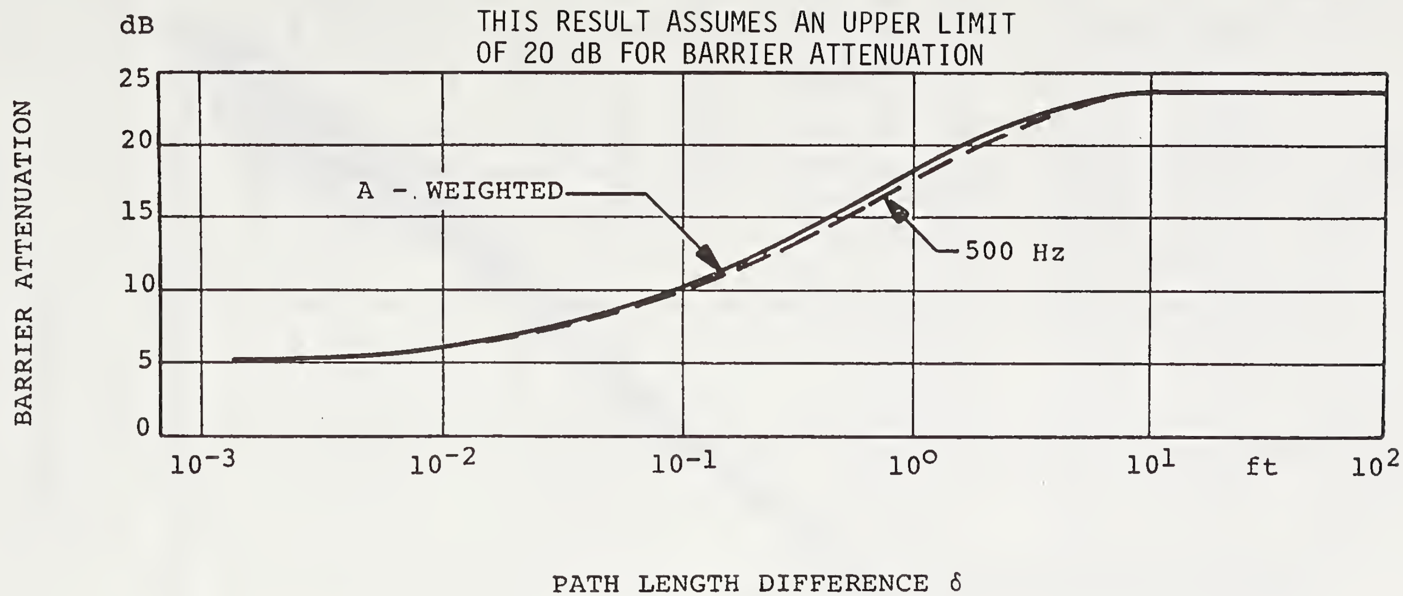


Figure A-4. BARRIER ATTENUATION AS A FUNCTION OF THE PATH LENGTH DIFFERENCE δ FOR A FREQUENCY OF 500 Hz AND FOR A-WEIGHTED LEVEL OF TYPICAL PASSENGER CAR NOISE

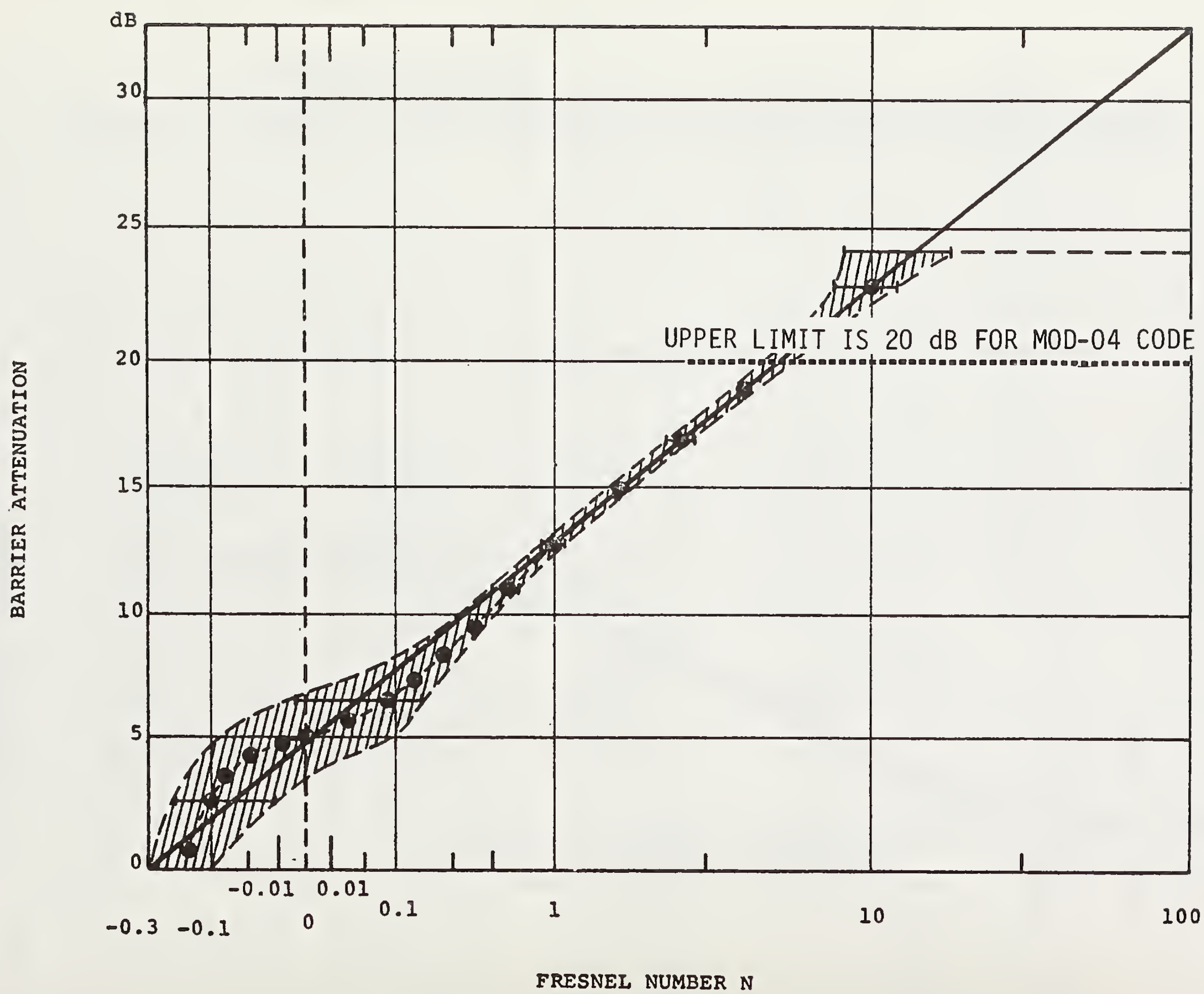


FIGURE A-5. BARRIER ATTENUATION AS A FUNCTION OF THE FRESNEL NUMBER FOR DIFFRACTION

The criterion used for the acceptance of a sufficiently small difference in path length differences (i.e., uniform attenuation) is:

$$|\delta_2 - \delta_1| - \frac{\delta_1 + \delta_2}{100}\left(1 + \frac{\delta_1 + \delta_2}{2}\right) \leq 0.1 \qquad \text{(A-21)}$$

The numbers are based on a frequency of 500 Hz, for which the effect of Equation(A-21)on the attenuation is plotted in Figure A-5.

In case of multiple diffraction by several barriers in parallel, the coded procedures consider the strongest diffraction exclusively.

This is a conservative procedure resulting in attenuations that are somewhat too small, but it seems to be the most reasonable way to bypass the very complicated and not yet fully understood problem of multiple diffraction.

A.7 GROUND ABSORPTION

Ground attenuation is a function of the structure and the covering of the ground, both of which influence its acoustic properties, and of the heights of the source and receiver above the ground.

For these procedures, a very simple approximation of rectangular ground strips is assumed, defined by two end points of a center line and by a width, and which have either a low cover such as shrubbery and thick grass, or a high cover, such as trees.

The height of a sound ray traveling from the source to the receiver over the ground strip is checked only with respect to the center line of the strip. Thus, it is assumed that the plane of the ground strip is approximately parallel to a plane defined by a road segment and a receiver. If the height of the direct sound

ray from the source to the receiver is more than 10 feet above a ground strip with a low cover or more than 30 feet above a ground strip with high cover, any sound attenuation due to ground absorption is neglected. The heights of 10 and 30 feet are based on rough estimates rather than on field experience and might be revised if found necessary.

In general, the amount of ground attenuation cannot be stated in terms of excess attenuation per unit of distance. To a first approximation, however, such behavior can be assumed in the range of distances of 200 to 2000 feet unless the total attenuation exceeds 20 dB (A-3).

No attempt has been made to calculate accurate distances over a ground strip with the computer program. Instead, a mean path length, r, over ground strips is calculated with the formula

$$r = \frac{\pi/2}{(1/w) + (1/\ell)} \qquad \text{(A-22)}$$

where w is the width of the strip and ℓ the length of the center line.

The following analytical approximations to average values of measured data are used to calculate the attenuation of sound propagating (A-3):

1) Through shrubbery and over thick grass

$$D_G = \left[0.18 \log (f) - 0.31\right] \frac{r}{3.28} \text{ dB}, \qquad \text{(A-23)}$$

(See Figure A-6)

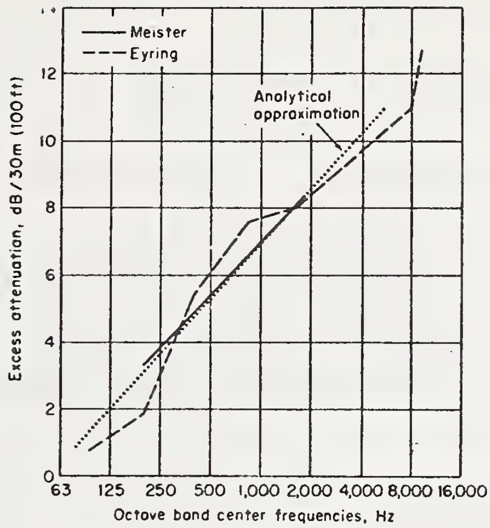


Figure A-6. ATTENUATION FOR SOUND PROPAGATION THROUGH SHRUBBERY AND OVER THICK GRASS, MEASURED DATA AND ANALYTICAL APPROXIMATION

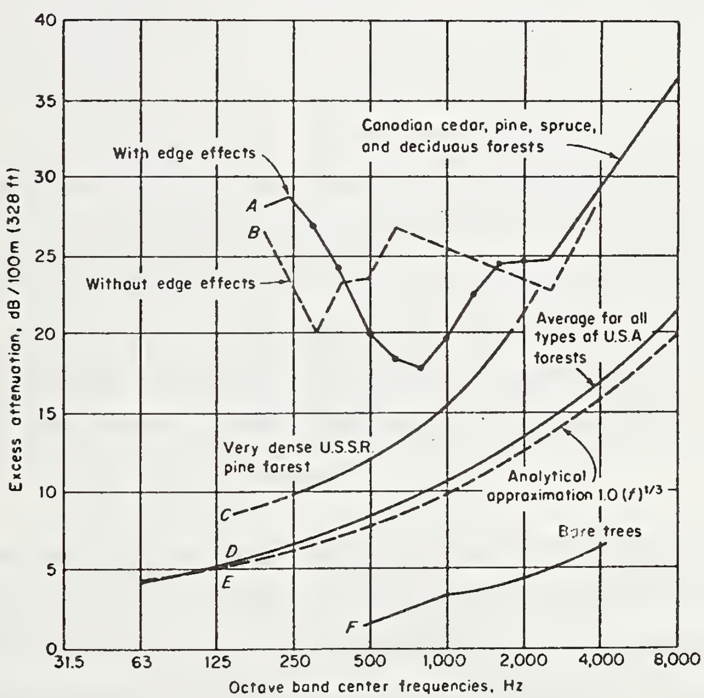


Figure A-7. ATTENUATION FOR SOUND PROPAGATION IN TREE ZONES, MEASURED DATA AND ANALYTICAL APPROXIMATION FOR AVERAGE USA FORESTS

2) Through tree zones

$$D_G = 0.01\,(f)^{1/3}\,r/3.28 \quad \text{dB} \tag{A-24}$$

(See Figure A-7)

where r is given in feet and f in Hz. With r in feet and with octave band index numbers n, where, for example, n = 5 for the octave band center frequency f = 500 Hz, these relations become, using Equation (A-15):

1) For shrubbery and thick grass

$$\begin{aligned} D_G &= (0.016n - 0.028)r \text{ dB} && \text{if } D_G \leq 20 \text{ dB} \\ D_G &= 20 \text{ dB} && \text{if } D_G > 20 \text{ dB} \end{aligned} \tag{A-25}$$

2) For tree zones

$$\begin{aligned} D_G &= (2^{n/3})\, r/131.2 \text{ dB} && \text{if } D_G \leq 20 \text{ dB} \\ D_G &= 20 \text{ dB} && \text{if } D_G > 20 \text{ dB} \end{aligned} \tag{A-26}$$

The notation in the second lines of Equations (A-25) and (A-26) indicate that the attenuation is limited to 20 dB based upon field experience (A-4).

Consistent with the assumption that the ground attenuation is proportional to the mean path length of the sound over the ground strip, the procedures accumulate attenuations of various ground strips in series. However, since the path length considered represents a statistical average for rays propagating in all directions over the strip, the path length over two equal, parallel strips is

not just twice the path length over a single strip of twice the width but is generally shorter. Consequently, the attenuation calculated for one strip will be smaller than the attenuation calculated for two strips in parallel each having half the width.

The purpose of using the statistical formulation for path length given by Equation (A-22) is to obtain reasonable predictions for the effects of ground absorption on an average basis. There exist, however, particular cases where the model will not be very accurate. For example, the attenuation of sound from a short road segment by long, narrow absorbing strips is overestimated, whereas the attenuation by a wide strip oriented perpendicularly to the road is underestimated. To some extent, these modeling errors compensate for one another in most practical situations. In general, inaccuracies are inherent to the entire problem of ground absorption.

A.8 REFLECTION

The sound field at a receiver results from contributions of direct (or diffracted) and reflected rays. In many practical cases of sound propagation from a highway, corrections applied for reflections are small compared to the inaccuracies involved in the prediction of ground attenuation and in uncertainties with acoustical shadow zones owing to wind and temperature gradients in the atmosphere. Therefore, the model has been designed to account for reflections with a first-order approximation.

The reflection model utilized by the traffic noise prediction code disregards phase relations between the various contributions and considers incoherent waves for which the total sound intensity is the sum of the intensities of the individual contributions.

Reflections from the road surface are always present. However, the contributions from these reflections are implicitly included

in reference levels at a short distance from individual vehicles on the road.

Reflections at the ground plane farther from the roadway are disregarded because they generally result in a complex interference pattern with the direct ray. Consideration of these effects is beyond the scope of a first-order approximation for reflections.

Reflections at any inclined plane result in rays directed either toward the ground, and thus being neglected, or toward the sky, and thus not contributing to the sound intensity at a normal receiver location close to the ground. Therefore, only reflections on planes that are perpendicular to the ground plane are considered by the prediction code.

Within the first-order approximation, this model also neglects the actual frequency-dependent magnitude of reflection coefficients and distinguish only between reflection coefficients 0 and 1 of reflecting surfaces (i.e., perfect absorption or perfect reflection, respectively).

In order to determine whether a reflective barrier is high enough to be effective, the procedures consider the possibly reflected ray that travels a minimum distance from the road segment to the receiver. A reflective plane perpendicular to the ground is considered high enough if the direct ray strikes the barrier at least 2 feet below the top edge of the barrier. For reflection points within 2 feet of the top edge, diffraction effects are considered by the model to be strong enough for all frequencies so that the reflected ray is sufficiently reduced in amplitude to be negligible.

Also neglected by the model are reflections from planes that are either very short or very remote so that the contribution to the sound intensity at the receiver is less than 10 percent of the intensity received via direct (or diffracted) rays from the road segment

under consideration. The analytical formulation for this criterion is

$$\frac{d\Delta\alpha'}{d'\Delta\alpha}\ 10^{-D_B/10} < 0.1 \tag{A-27}$$

where d = distance from the receiver to the road segment in feet

$\Delta\alpha$ = aspect angle of the road segment at the receiver

d' = distance from the road segment to a receiver location imaged about the reflector

$\Delta\alpha'$ = aspect angle of the barrier at the image receiver

D_B = attenuation in dB by diffraction of the direct ray due to a possible barrier (referred to a frequency of 500 Hz).

Single reflections are considered exclusively; contributions from rays that strike two or more reflectors are ignored. It is essential for the future calculation of higher order statistical parameters of road traffic noise that the reflections of sound from a certain road segment be treated as amplifications of the direct (or diffracted) rays and not as uncorrelated contributions from independent road segments. The factor F multiplying the intensity of the direct sound from a road segment is calculated in Subroutine GEOMRY using

$$F = 10^{-D_B/10} + \sum_{i=1}^{N} \frac{\Delta\alpha_i' d}{\Delta\alpha d_i'}\ 10^{-D_i/10} \tag{A-28}$$

where the subscript i indicates reflections at N different surfaces, each of which might be diffracted by a barrier before or after reflection and therefore might have an attenuation D_i. The factor F is

calculated as a function of frequency. The notation in Equation (A-28) is the same as in Equation (A-27) except for the angle $\Delta\alpha'$ which denotes the aspect angle of the road segment at the image receiver (Figure A-8).

A.9 COMBINATION OF ATTENUATION AND REFLECTION

A.9.1 Atmospheric Absorption

The overall procedures account for atmospheric absorption in combination with barrier diffraction, ground absorption and reflections. The path length used for calculating the atmospheric absorption is the direct distance from the source to the receiver and is not corrected for the path length difference δ of diffracted rays nor for the increased path length of reflected rays. The factor F, defined by Equation (A-28) is multiplied by $10^{-D_A/10}$, where D_A is defined by Equation (A-16), in order to calculate, for each individual road segment, the factor

$$10^{-D/10} = F \cdot 10^{-D_A/10} \cdot 10^{-D_G/10} \qquad \text{(A-29)}$$

This composite attenuation factor is employed for the calculation of the energy mean level in Equations (A-9) and (A-11).

A.9.2 Ground Absorption

The prediction procedure includes ground absorption if such attenuation is significant only for the case of no diffraction of sound from the source to the receiver. That is, if in analyzing a <u>sub</u>-segment of a roadway segment, diffraction of the direct ray from the source to the receiver is encountered, the prediction code ignores the attenuation resulting from ground cover of all types for the <u>sub</u>-segment of roadway being analyzed. As indicated by Equation (A-29), the same ground absorption is assumed for both the direct rays and for all reflections.

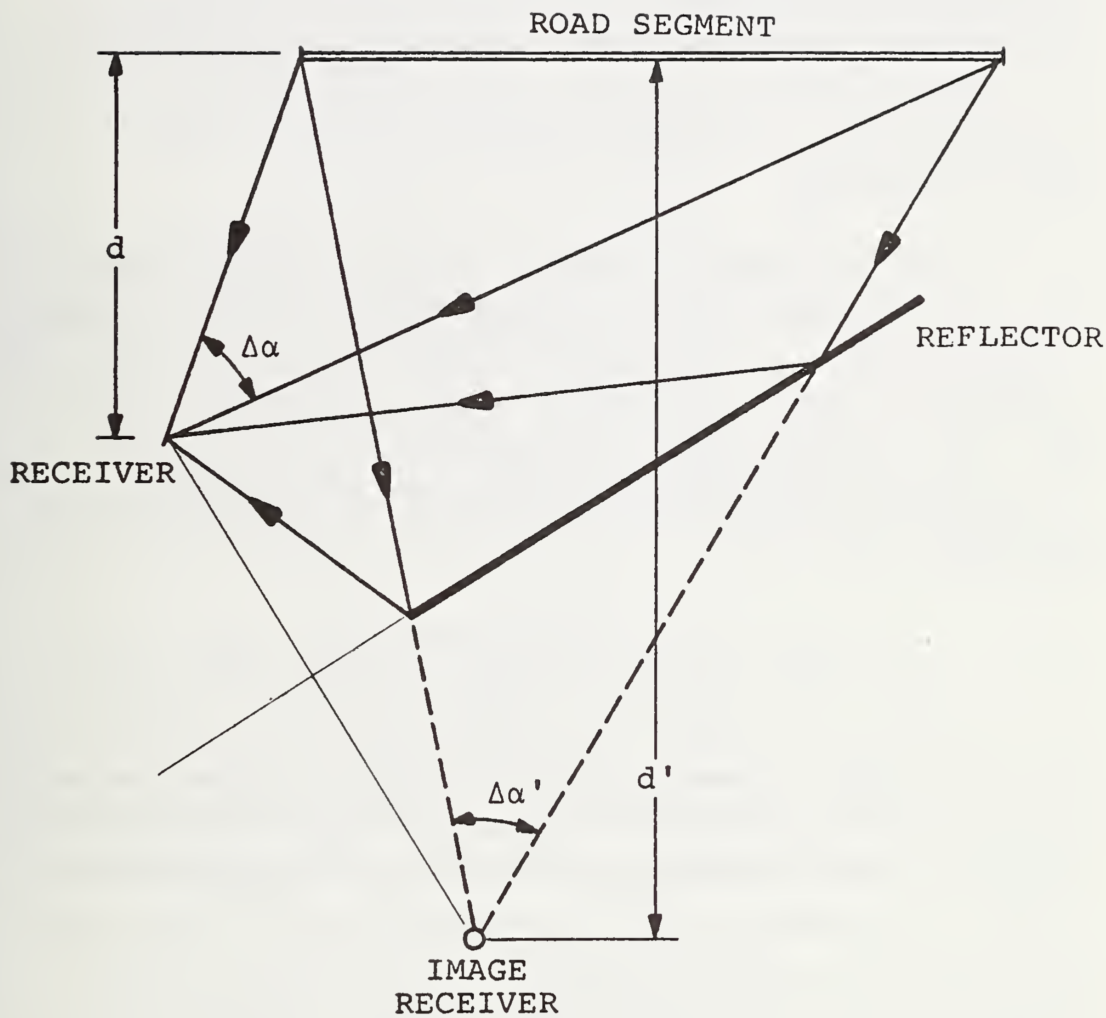


Figure A-8. EXAMPLE FOR RAY TRACES FROM A REFLECTOR, INDICATING THE CONSTRUCTION BY MEANS OF AN IMAGE RECEIVER

A.9.3 Reflection Before or After Diffraction

The procedures account for reflections in combination, with diffraction provided that there is only a single diffraction before or after the reflection and that the path length increase due to diffraction is less than 5.6 feet. Doubly diffracted reflections are neglected as well as very weak single reflections that suffer, in the 500 Hz band, the maximum attenuation of 20 dB assumed for barrier diffraction.

The attenuation of reflected rays by diffraction is calculated for one location on the road segment only: the point nearest to the image receiver. No attempt is made to refine this calculation by checking for the attenuation from other points on the road segment, since the contribution of diffracted reflections will be generally small and, hence, inaccuracies of the calculation will be negligible.

A.10 FLUCTUATIONS OF NOISE FROM FREELY FLOWING HIGHWAY TRAFFIC

Due to the random fluctuation of sound levels, the noise from road traffic is often described by statistical means. Generally, the sound levels are described in terms of A-weighted sound pressure levels, L_x, that are exceeded x percent of the time ("percentile levels"). The level L_{50}, that is exceeded 50 percent of the time, and the level L_{10}, that is exceeded 10 percent of the time, are frequently used as single number descriptors of fluctuating road traffic noise. Combinations of these levels with the level L_{90} result in Robinson's original definition of the Noise Pollution Level (A-7).

$$L_{NP} = L_e + L_{10} - L_{90}, \text{ dB} \qquad \text{(A-30)}$$

which, for a Gaussian or normal distribution of sound pressure levels, is identical with the relationship

$$L_{NP} = L_{50} + (L_{10} - L_{90}) + \frac{(L_{10} - L_{90})^2}{57}, \text{ dB} \qquad \text{(A-31)}$$

The energy mean level L_e and the standard deviation σ_L of the sound pressure level are employed in the more general definition of the Noise Pollution Level:

$$L_{NP} = L_e + 2.56\ \sigma_L, \text{ dB} \qquad \text{(A-32)}$$

To predict percentile levels, it is necessary to find the distribution function of the sound pressure level or of the sound intensity. It has been recently shown that certain factors*, κ_n, can be calculated for freely flowing road traffic. (Effects of queuing or platooning are neglected.) In a first-order approximation, the factor κ_2, which is the variance of the sound intensity normalized by its mean, is related to the standard deviation σ_L of the sound pressure level by (A-8)

$$\sigma_L = 4.35\ \sqrt{\ln(1 + \kappa_2)}, \text{ dB} \qquad \text{(A-33)}$$

$$\ln(x) = \log_e(x)$$

This relation is exact for a Gaussian or normal distribution of sound pressure levels. In the first-order approximation utilized by the prediction code, deviations of actual distribution functions from the Gaussian distribution are neglected and percentile levels expressed as:

$$L_{50} = L_e - \frac{\sigma_L^2}{8.7}, \text{ dB} \qquad \text{(A-34a)}$$

$$L_{10} = L_{50} + 1.28\ \sigma_L, \text{ dB} \qquad \text{(A-34b)}$$

$$L_{90} = L_{50} - 1.28\ \sigma_L, \text{ dB} \qquad \text{(A-34c)}$$

The factors, κ_n, of the sound intensity, when normalized by the mean value I given by Equation (A-9) are expressed as:

* Called cumulants

$$\kappa_n = \left(\frac{r_o^2}{I}\right)^n \sum_{j=1}^{R} \left\{ \frac{C_{n-1}}{d^{2n-1}} \sum_{i=1}^{N} \lambda_i 10^{n(\bar{L}_{o,ij}-D_{ij})/10} e^{0.5(n\sigma_{o,ij}/4.35)^2} \right\} \quad \text{(A-35a)}$$

where $4.35 \approx 10/\ln(10)$; j denotes a roadway; i denotes a vehicle class

I is given by Equation (A-9);

$C_o = \alpha_2 - \alpha_1$; and

$$C_n = \frac{1}{2n}\left[\sin\alpha_2 \cos^{2n-1}\alpha_2 - \sin\alpha_1 \cos^{2n-1}\alpha_1 + (2n-1)C_{n-1}\right] \quad \text{(A-35b)}$$

are functions of the angles α_1 and α_2 as defined in Figure A-1, and can be calculated by the given recurrence relation.

Note that all the other parameters involved in Equation (A-35) namely, d, λ, D, L_o, and σ_o are the same as those defined for Equation (A-8) and are already computed by the basic program.

In dealing with statistical distributions of sound pressure levels, it is common practice that the levels are A-weighted levels at the receiver. Consequently, the factors describing the statistical distribution are expressed in terms of overall A-weighted sound levels.

As mentioned in Section A.3, the prediction code conducts independent calculations for the overall A-weighted sound level and the eight octave bands from 63 Hz to 8000 Hz, as specified by the user. Both the overall level and the octave band levels are calculated using the basic result of Equation (A-12). However, if the user specifies that all eight octave band levels be calculated, the prediction code calculates the energy mean level as the intensity summation of the octave band levels and prints this result as the value for the energy mean level, "LE(A)". The independently calculated value for the energy

mean level, "LE(A)," is printed if the user specifies less than eight octave band level predictions. The independent calculation of "LE(A)" utilizes Equation (A-12). The standard deviation of the highway traffic noise utilizes the results of Equations (A-33) and (A-35). The independently calculated value of LE(A) will always be greater than the octave band summation by a fraction of a dBA unit. The reason for this slight difference is a result of the frequency dependence of attenuation factors for the octave band calculations and should not be a practical concern to the user.

REFERENCES

Appendix A

A-1 Private communication with authors from Dr. T.M. Barry, Office of Research, Federal Highway Administration, November 1976.

A-2 Wasler, J.E.: "Manual for Highway Noise Prediction," U.S. Department of Transportation, Federal Highway Administration, Report No. DOT-TSC-FHWA-72-1 (Appendix B, separately bound), March 1972.

A-3 Kurze, U.J. and Beranek, L.L.: "Sound Propagation Outdoors," in L.L. Beranek (ed.) Noise and Vibration Control, McGraw-Hill Book Company, New York, 1971, p. 170.

A-4 Private Communication with authors from Mr. J. E. Wesler, U.S. Department of Transportation, November 1976.

A-5 Maekawa, Z: "Noise Reduction by Screens," Applied Acoustics, Vol. 1, 1968, pp. 157-173.

A-6 Kurze, U.J., and Anderson, G.S.: "Sound Attenuation by Barriers," Applied Acoustics, Vol. 4, 1971, pp. 35-53.

A-7 Robinson, D.W.: "Towards a Unified System of Noise Assessment," Journal of Sound and Vibration, Vol. 14, No. 3, 1971, pp. 279-298.

A-8 Kurze, U.J.: "Noise from Complex Road Traffic," Journal of Sound and Vibration, Vol. 19, No. 2, 1971, pp 167-177.

APPENDIX B

DECLARED SIZE OF ARRAYS

B.1 PARAMETERS DEFINING THE PROBLEM

The basic parameters used by the prediction code and upon which the declared size of an array depends are as follows:

- Number of Roadways, NR: Declared as 20
- Number of Roadway Sections, NRSM1(NR): Declared as 10
- Number of Vehicle Types, NQ: Declared as 4
- Number of Traffic Flow Conditions on a Roadway, NQS(NR,NQ): Declared as 5
- Number of Receivers, NRC: Declared as 15
- Number of Octave Frequency Bands, NF: Declared as 9
- Number of Barriers, NB: Declared as 20
- Number of Barrier Segments, NBSM1(NB): Declared as 10
- Number of Ground Strips, NG: Declared as 10
- Number of Types of Ground Strips, IDUM(NG): Declared as 2
- Number of Allowable Reflections, IDXR: Declared as 10
- Number of Program Initialization Parameters, IP: Declared as 6

The following sections of this appendix define the declared size of all arrays depending upon the above parameters. Arrays not explicitly presented in the following sections are used to describe coordinates in (x,y) space (declared as 2) or (x, y, z) space (declared as 3) and the usage should be evident to the user.

B.2 MAIN PROGRAM - GENERAL DIMENSION STATEMENTS

The arrays listed below with general dimension statements appear in the MAIN PROGRAM. The user should refer to the parameter list in Section B.1

RDIN(IP)

XRC(NRC),YRC(NRC),ZRC(NRC)

NQS(NR,NQ)

XLE(NF)

XMPH(NR,NQS,NQ),VEXPH(NR,NQS,NQ)
RX(NR,NRSM1+1),RY(NR,NRSM1+1),RZ(NR,NRSM1+1)
NRSM1(NR)

B.3 BLOCK DATA-GENERAL DIMENSION STATEMENTS

The arrays listed below with general dimension statements appear in BLOCK DATA. The user should refer to the parameter list in Section B.1.

CO(NF,NQ),C1(NF,NQ),C2(NF,NQ)
SO(NF,NQ),S1(NF,NQ),S2(NF,NQ)

B.4 SUBROUTINE INPUT-GENERAL DIMENSION STATEMENTS

The arrays listed below with general dimension statements appear in subroutine INPUT. The user should refer to the parameter list in Section B.1.

NQS(NR,NQ),VTEMP(NQ)
BX(NB,NBSM1+1),BY(NB,NBSM1+1),BZ(NB,NBSM1+1)
IBLAST(NB),NBSM1(NB)
XXG1(NG,IDUM),YYG1(NG,IDUM), ZZG1(NG,IDUM)
BGS(NG),IDUM(NG)
RX(NR,NRSM1+1),RY(NR,NRSM1+1),RZ(NRSM1+1)
NRSM1(NR)
XMPH(NR,NQS,NQ),VEXPH(NR,NQS,NQ)
RDIN(IP)
XRC(NRC),YRC(NRC),ZRC(NRC)
CO(NF,NQ),C1(NF,NQ),C2(NR,NQ),SO(NF,NQ),S1(NF,NQ)
S2(NF,NQ)

B.5 SUBROUTINE CHECK-GENERAL DIMENSION STATEMENTS

The arrays listed below with general dimension statements appear in subroutine CHECK. The user should refer to the parameter list in Section B.1

BX(NB,NBSM1+1),BY(NB,NBSM1+1),BZ(NB,NBSM1+1)
IBLAST(NB),NBSM1(NB)
XXG1(NG,IDUM),YYG1(NG,IDUM),ZZG1(NG,IDUM)
BGS(NG),IDUM(NG)
RX(NR,NRSM1+1),RY(NR,NRSM1+1),RZ(NR,NRSM1+1)
NRSM1(NR)

B.6 SUBROUTINE INTER-GENERAL DIMENSION STATEMENTS

The arrays listed below with general dimension statements appear in subroutine INTER. The user should refer to the parameter list in Section B.1.

CO(NF,NQ),C1(NF,NQ),C2(NF,NQ),SO(NF,NQ),S1(NF,NQ)
S2(NF,NQ)
XMPH(NR,NQS,NQ),VEXPH(NR,NQS,NQ),NQS(NR,NQ)
XLREF(NR*NQS*NF*NQ),CQ(NR*NQS*NF*NQ)

B.7 SUBROUTINE GEOMRY-GENERAL DIMENSION STATEMENTS

The arrays listed below with general dimension statements appear in subroutine GEOMRY. The user should refer to the parameter list in Section B.1.

B1(3,2,NB*(NBSM1+1)),R1(3,2,NB*(NBSM1+1)),
RB1(3,2,NB*(NBSM1+1)),TA1(3,2,NG),
KBCODE(NB*(NBSM1+1)),KNUMB(NB*(NBSM1+1)),
KRNUMB(NB*(NBSM1+1)), KRDNUM(NB*(NBSM1+1))
KGCODE(NG),BGT(NG),IKIN(NG),BGS(NG),IDUM(NG),
DELPO(NQ),DELP1(NQ),DELP2(NQ),FB(NF,NQ),
DELR(NQ,IDXR),FG(NF),HGA(IDUM),
XIMG(3,IDXR),ZS(NQ),RDIN(IP),NQS(NR,NQ),
XLE(NF),XMPH(NR,NQS,NQ),VEXPH(NR,NQS,NQ),
BX(NB,NBSM1+1),BY(NB,NBSM1+1),BZ(NB,NBSM1+1),
IBLAST(NB),NBSM1(NB),XXG1(NG,IDUM),YYG1(NG,IDUM),
ZZG1(NG,IDUM),XLREF(NR*NQ*NF*NQS),
CQ(NR*NQ*NF*NQS).

APPENDIX C

ALLOCATION OF COMMON BLOCK DATA

Table C-1, below, indicates the allocation of common block data within the highway traffic noise prediction code. The user may refer to the listings in Appendix C and Appendix E, as appropriate, for the variables assigned to each common block.

TABLE C-1

ASSIGNMENT OF COMMON BLOCK DATA

COMMON BLOCK TITLE	MAIN PROGRAM	BLOCK DATA	INPUT	CHECK	INTER	DEGEN	GEOMRY
/INOU/	●	●	●	●	x	●	●
/STORE1/	x	x	●	●	x	x	●
/STORE2/	x	x	●	●	x	x	●
/STORE3/	●	x	●	●	x	x	x
/STORE4/	●	x	●	x	●	x	●
/INPT1/	●	x	●	x	x	x	●
/INPT2/	●	x	●	●	x	x	●
/INPT3/	x	x	●	x	x	x	x
/DRIV2/	x	x	●	x	●	x	●
/DRIV3/	●	x	x	x	x	x	●
/DRIV4/	●	x	x	x	x	x	●
/BLK2/	●	x	●	x	x	x	●
/CONSTS/	x	●	●	x	x	x	●
/GEO1/	●	x	x	x	x	x	●
/INTER1/	x	x	x	x	●	x	●

● Denotes Assignment of Common
x Denotes No Assignment of Common

APPENDIX D

ARCHITECTURE OF PREDICTION CODE

D.1 INTRODUCTION

The version of the highway traffic noise prediction code described in this manual differs slightly from previous versions (See Section 2.) of the code. As compared to the 1974 version, the user will note that the present version includes an additional subroutine called CHECK and a BLOCK DATA subprogram. The complete program comprises the MAIN PROGRAM and thirty (30) subprograms. The data management within the code is accomplished by MAIN, INPUT, and GEOMRY. The subroutines calculating acoustical parameters are BLOCK DATA, INTER, BARFAC, and IEPS. The 23 remaining subprograms are related to the geometric description of the problem.

The program is written in FORTRAN IV language and is intended to run in the batch mode. As described in this manual, data input is via a card reader and output is via a line printer (See Appendix C; COMMON/INOU/).

The MAIN program is described in detail in this appendix. Detail descriptions of the subprograms are provided in appendix. Following the description of each subprogram, the listing for that block of code is presented. The organization of the prediction code is illustrated in Figure D-1.

D.2 MAIN PROGRAM DESCRIPTION

The MAIN program controls the flow of operations required to perform the highway traffic noise estimates at each receiver. The MAIN program calls various subprograms that conduct the bulk of the calculations. The basic program variables initialized by the MAIN program are NQ=3, NG=0, and NB=0 (i.e., three vehicle types, no absorptive ground strips, and no barriers).

The main program immediately reads and prints the user-defined title. Next, the MAIN program calls SUBROUTINE INPUT to read the input data defining the problem (See Section 6 and Appendix E). If the user fails to properly define a roadway and/or a barrier by at least two end points, an error message is printed and the MAIN program attempts to read the next data set (See Section 5.8).

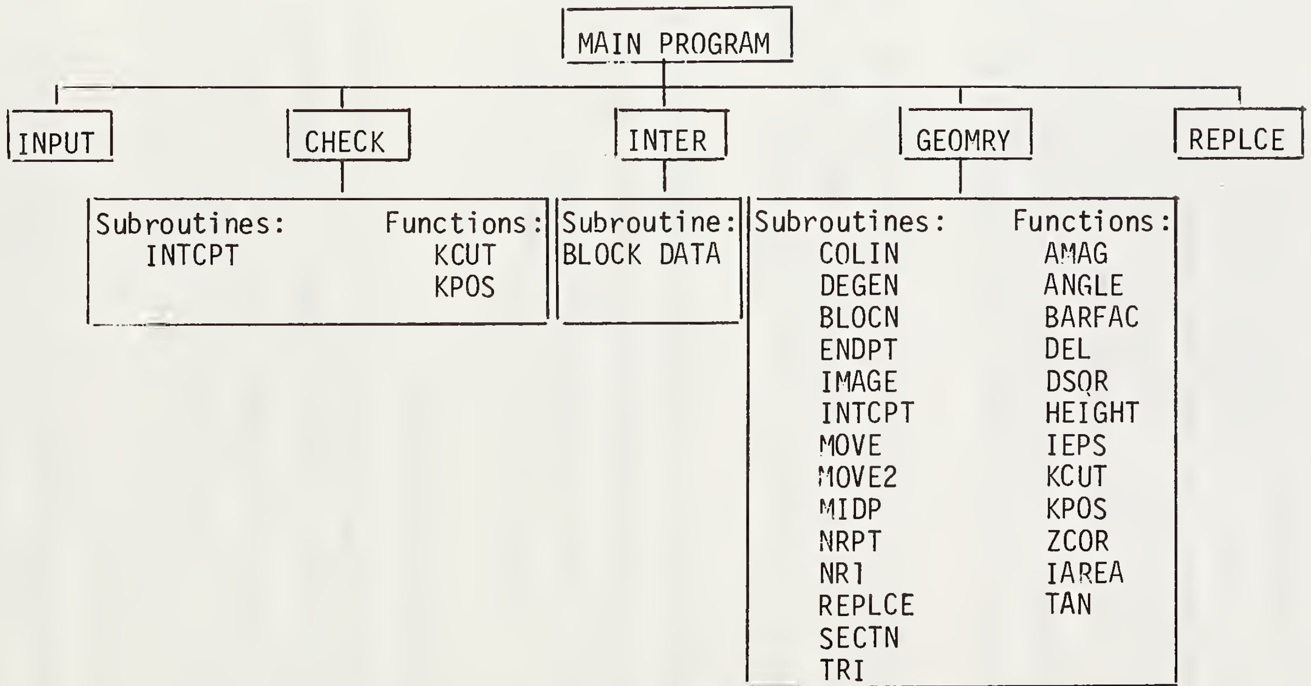


FIGURE D-1 ARCHITECTURE OF PREDICTION CODE :MOD-04

Following execution of INPUT, the MAIN program calls SUBROUTINE CHECK to determine if either a barrier segment or an absorptive ground strip center line intersect a roadway segment. If such an intersection occurs an error message is printed for each such intersection (See Section 5.8). Following the execution of CHECK, the MAIN program is ready to begin sound level estimates if no errors have been encountered.

The MAIN program next calculates the reference distance sound levels and standard deviations for each vehicle type, traffic flow condition, and each frequency band specified for all roadways. This calculation is conducted by SUBROUTINE INTER. Following execution of subroutine INTER, the MAIN program begins the receiver sound level estimates in the following sequence:

The array, XLE(J), is initialized to zero. This array contains the normalized values of the acoustic intensity at the receiver for the overall A-weighted intensity, XLE(1), and the A-weighted octave band intensity (XLE(J),J=2,9).

The MAIN program next selects the roadway number and initializes the coordinates of the first end point of the roadway segment (array, XR1(J)). The next end point of the roadway segment is specified (array XR2(J)) and the basic problem is defined for the prediction code (i.e., roadway segment/receiver geometry. See Section 3.1).

To perform the calculations related to the basic problem defined for the code, the MAIN program calls subroutine GEOMRY. The vast bulk of the calculations performed by the prediction code are conducted in subroutine GEOMRY. If no errors are encountered in subroutine GEOMRY (See Section 5.8), the MAIN program continues the roadway analysis for each roadway segment until all roadways have been considered. The normalized acoustic intensity is accumulated in the array XLE(J) in subroutine GEOMRY.

Following the analysis of all roadways (sources) for the specified receiver, the MAIN program next calculates the standard deviation, SIGL, for the composite traffic noise and adjusts the normalized acoustic

intensity, XLE(J), into absolute units of sound level (also stored in array XLE(J)). The main program then calculates the sound level descriptors LE(A) (XLE(1)), L50, L10, and L90. The output data is pinted for the specified receiver and the MAIN program selects the next receiver continuing the above sequence until all receivers have been considered.

The flow diagram for the main program is illustrated in Figure D-2. Statement numbers are presented at points on the flow diagram so that the user may refer to specific blocks of code as required.

D.3 MAIN PROGRAM VARIABLE LIST

The variables used in the MAIN program are listed below. Array variables are not indicated as such; however, the user may refer to Appendix B, as required, to determine appropriate array sizes. Variables not listed are described in the subprograms where they are utilized.

CAP2	Cumulant for the A-weighted acoustic intensity
I	Index for receiver loop
IQ	Index for vehicle type
J	Index for frequency band
M	Index for roadway number
N	Index for road section number
NB	Number of barriers
NF	Number of frequency bands
NG	Number of absorptive ground strips
NLIM	Number of points defining a roadway
NQ	Number of vehicle types
NQS	Vector notation for number of vehicle types for each roadway
NR	Number of roadways
NRC	Number of receivers
NRSM1	Number of sections for one roadway
RDIN	Vector notation for initialization parameters
RX	x-coordinate of roadway point
RY	y-coordinate of roadway point
RZ	z-coordinate of roadway point
SIGL	Standard deviation of A-weighted sound intensity
XAL	Energy mean A-weighted overall sound level

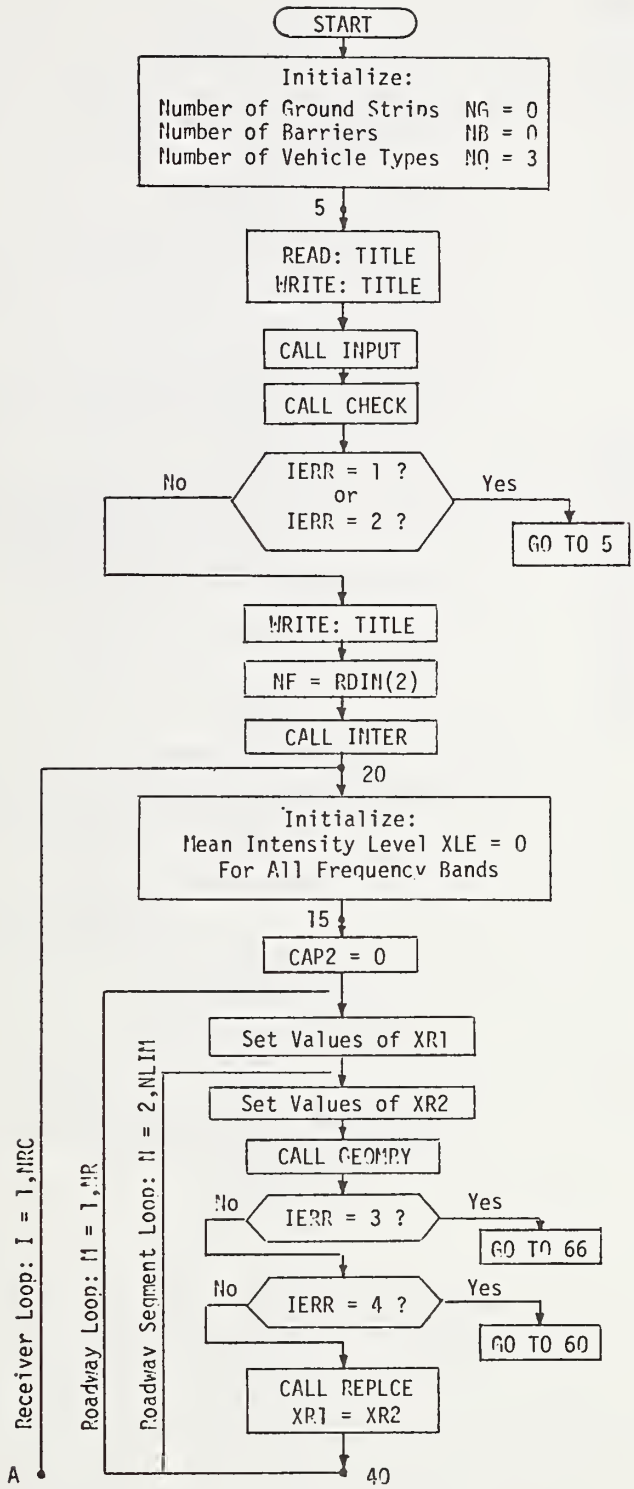


FIGURE D-2. MAIN PROGRAM FLOW DIAGRAM (Continued)

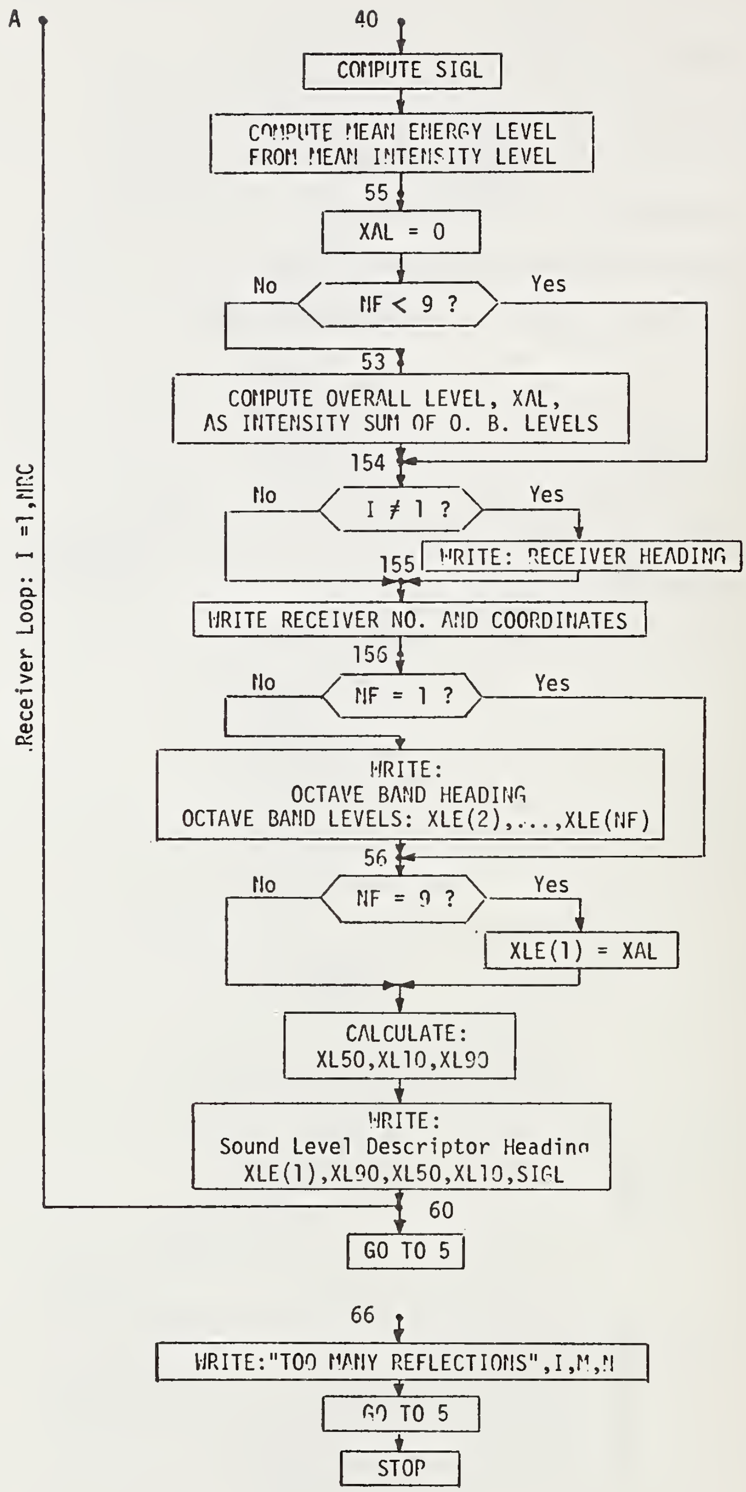


FIGURE D-2 (Concluded)

XLE	Energy mean A-weighted intensity and level in frequency bands
XL10	A-weighted sound exceeded 10% of the time
XL50	A-weighted sound exceeded 50% of the time
XL90	A-weighted sound exceeded 90% of the time
XR1	Road section initial point
XR2	Road section end point
XRC	x-coordinate of receiver
YRC	y-coordinate of receiver
ZRC	z-coordinate of receiver

D.4 MAIN PROGRAM LISTING

The block of code comprising the MAIN program of the highway traffic noise prediction code is presented in the listing on the following pages.

```
C    TRAFFIC NOISE PREDICTION MODEL
C    MAIN PROGRAM   12/76    SAI MOD
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION XR1(3),XR2(3)
      COMMON/INOU/INPT,IOUT
      COMMON/BLK2/NQ
      COMMON /INPT1/RDIN(6)
      COMMON/INPT2/NR,NB,NG
      COMMON/INPT3/XRC(15),YRC(15),ZRC(15),NRC
      COMMON/DRIV2/NQS(20,4),NF
      COMMON /DRIV3/XLE(9)
      COMMON/STORE4/XMPH(20,5,4),VEXPH(20,5,4)
      COMMON/DRIV4/CAP2
      COMMON/STORE3/RX(20,11),RY(20,11),RZ(20,11),NRSM1(20)
      COMMON/GEO1/IBAR,ISEG,IGRA
      INTEGER TITLE(40)
C   NUMBER OF VEHICLE TYPE IS SET TO 3 IN THIS PROGRAM
      NG=0
      NB=0
      NQ = 3
    5 READ(INPT,1005,END=999)(TITLE(I),I=1,40)
      WRITE(IOUT,2009)
      WRITE(IOUT,1005) (TITLE(I),I=1,40)
      CALL INPUT
      CALL CHECK(IERR)
      IF (IERR.EQ.1.OR.IERR.EQ.2) GO TO 5
      WRITE(IOUT,1002)(TITLE(I),I=1,40)
      WRITE(IOUT,1003)
      NF=RDIN(2)
C   PERFORM INTERPOLATION
      DO 20 M=1,NR
      DO 20 IQ=1,NQ
      NQC1=NQS(M,IQ)
      IF (NQC1.NE.0) CALL INTER(M,IQ)
   20 CONTINUE
```

MAIN PROGRAM: LISTING (Continued)

```
C   MAIN LOOP OF PROGRAM
        DO 60 I=1,NRC
        DO 15 J=1,NF
        XLE(J)=0.
   15   CONTINUE
        CAP2=0.0
        DO 40 M=1,NR
        XR1(1)=RX(M,1)
        XR1(2)=RY(M,1)
        XR1(3)=RZ(M,1)
        NLIM=NRSM1(M)+1
        DO 40 N=2,NLIM
        XR2(1)=RX(M,N)
        XR2(2)=RY(M,N)
        XR2(3)=RZ(M,N)
        CALL GEOMRY(XRC(I),YRC(I),ZRC(I),XR1,XR2,IERR,M)
        IF(IERR.EQ.3)GO TO 66
        IF(IERR.EQ.4)GO TO 60
        CALL REPLCE(XR2,XR1)
   40   CONTINUE
        SIGL=4.35*DSQRT(DLOG(1.0+CAP2/XLE(1)**2))
        DO 55 J=1,NF
        XLE(J)=10.+10.*DLOG10(XLE(J))
   55   CONTINUE
C   COMPUTE SUM OF ALL OCTAVE BAND LEVELS
        XAL = 0.
        IF (NF.LT.9) GO TO 154
        DO 53 J=2,NF
   53   XAL = XAL + 10. ** (XLE(J)/10.)
        XAL = 10. * DLOG10(XAL)
  154   IF (I.NE.1) WRITE(IOUT,1003)
  155   WRITE(IOUT,1004) I,XRC(I),YRC(I),ZRC(I)
  156   IF(NF.EQ.1) GO TO 56
        WRITE(IOUT,2010)
        WRITE(IOUT,2001)
```

MAIN PROGRAM: LISTING (Continued)

```
      WRITE(IOUT,2002) (XLE(II),II=2,NF)
 56   IF (NF.EQ.9) XLE(1)=XAL
      XL50=XLE(1)-SIGL**2/8.7
      XL10=XL50+1.28*SIGL
      XL90=XL50-1.28*SIGL
      WRITE(IOUT,2003)
      WRITE(IOUT,2004)XLE(1),XL90,XL50,XL10,SIGL
   6  CONTINUE
      GO TO 5
  66  WRITE(IOUT,1009)I,M,N
      GO TO 5
 999  STOP
1002  FORMAT(//40A2)
1003  FORMAT(11H RECEIVER   10X,3HXRC9X,3HYRC9X,3HZRC)
1004  FORMAT(4X,I3,5X,3F12.1)
1005  FORMAT(40A2)
1009  FORMAT(26H TOO MANY REFLECTIONS,RCV ,I2,4H  R ,I2,4H  S ,I2)
2001  FORMAT( 14X,2H635X,3H1254X,3H2504X,3H5003X,4H10003X,4H20003X,
     X 4H4000 3X,4H8000)
2002  FORMAT(10X,8F7.1)
2003  FORMAT(/10X,5HLE(A),5X,3HL90,5X,3HL50,5X,3HL10,
     X        4X,5HSIGMA)
2004  FORMAT(8X,6F8.1//)
2009  FORMAT(1H1,15X,24HTRAFFIC NOISE PREDICTION//)
2010  FORMAT(/25X,22HOCTAVE BAND LEVELS (A))
      DEBUG SUBCHK
      END
```

MAIN PROGRAM: LISTING (Concluded)

APPENDIX E

SUBPROGRAM DESCRIPTIONS

This appendix contains the descriptions of the thirty (30) subprograms utilized by the prediction code to estimate highway traffic sound level estimates. The code utilizes 19 Subroutine subprograms and 11 Function subprograms. Each subprogram is described as an independent block of text using a standardized format.

For each subprogram the following format is used to describe the subprogram:

PURPOSE: The purpose of the subprogram is described

SUBPROGRAMS USED: The subprograms used by the subprogram are listed.

VARIABLES: The variables used by the subprogram are described in sequence: Input parameters, subprogram parameters, output parameters

RESTRICTIONS: Any restrictions that should be recognized by the user are described

ACCURACY: The accuracy of the subprogram is described (if appropriate)

SIZE: The compiled size of the subprogram is given in octal

REFERENCES: Any appropriate references are listed

FIGURES: Any figures required to understnad the subroutine are presented.

LISTING: The subprogram is listed.

E.1 SUBROUTINE INPUT

PURPOSE: Performs all inputs to the program, except for the title cards which are read in from MAIN. All input data are stored in common blocks and listed.

SUBROUTINES USED: None.

VARIABLES:

Input Parameters

NQ - Number of vehicle types.

Subroutine Parameters

NQ4 - a flag to indicate the existence of type 4 vehicles.

VALUE - Initialization parameter.

IDN - Index for program initialization parameter.

ILAST - Indicator for last card of a group of data.

ALPHA(I) - Optional alphanumeric information provided by user.

RDIN(IDN) - Array for storing initialization parameters

I - Index.

BLNK - Alphanumeric constant "ƀ ƀ".

ALP1(I,IDN) Default initialization parameters description.

LAST - Alphanumeric constant "L".

IGO - Index for data blocks.

I1 - Number of items in data block.

I2 - Dummy variable.

VEH - Number of vehicles per hour.

XMH - Speed in mph for the group of vehicles in question.

ITY - Vehicle type.

J - Index.

K - Index.

NSEC - Section number.

NQC1 - Vehicle group number within one vehicle type and one roadway.

SUBROUTINE INPUT (Continued)

IA	- Alphanumeric constant 'A'
IR	- Alphanumeric constant 'R'
IG	- Alphanumeric constant 'G'
IT	- Alphanumeric constant 'T'
IRDUM	- Dummy variable
XNIGHT	- Equivalent to RDIN(1), receiver height adjustment.

<u>Output Parameters</u>

NR	- Number of roadways
NRSM1(J)	- Number of sections for 1 roadway
RX(J,NSEC), RY(J,NSEC), RZ(J,NSEC)	Coordinates for the endpoints of roadway sections
CØ(I,4), C1, SØ(I,4)	User defined spectra for sound level and standard deviation for Type 4 vehicle
NQS(J,ITY)	- Number of vehicle groups per vehicle type per roadway
VEXPH(I,J,K)	Number of vehicles per type per hour
XMPH(I,J,K)	Vehicle speed in mph per group per vehicle type per roadway
NB	- Number of barriers
NBSM1(J)	- Number of sections for 1 barrier
IBLAST(J)	- Barrier type
BX(J,NSEC), BY(J,NSEC), BZ(J,NSEC)	Coordinates for the endpoint of barrier sections
NG	- Number of ground strips
XXG1(I,J), YYG1(I,J), ZZG1(I,J)	Coordinates for the endpoints of ground strips
BGS(I)	- Width of absorptive ground strip
IDUM(I)	- Type of absorptive ground strip

SUBROUTINE INPUT (Continued)

	NRC	- Number of receivers
	XRC(I) YRC(I) ZRC(I)	Receivers coordinates
RESTRICTIONS:	Input vehicle speed should be within the range of 20-70 mph. Speed less than 20 mph will be adjusted by the program to 20. Speed over 70 mph will be adjusted to 70. If data for type 4 vehicle is provided, the number of vehicle types is 4, otherwise, it is defaulted to 3. If the user desires to allow speed dependence for user-defined Type 4 vehicle, the comment cards following lines 40 and 41 in the program listing should be removed. This data would be entered in the program initialization parameter data block. See Sections 3.2, 6.0, and Appendix A, Section A.2.	
SIZE:	5524_8	
References:	None	

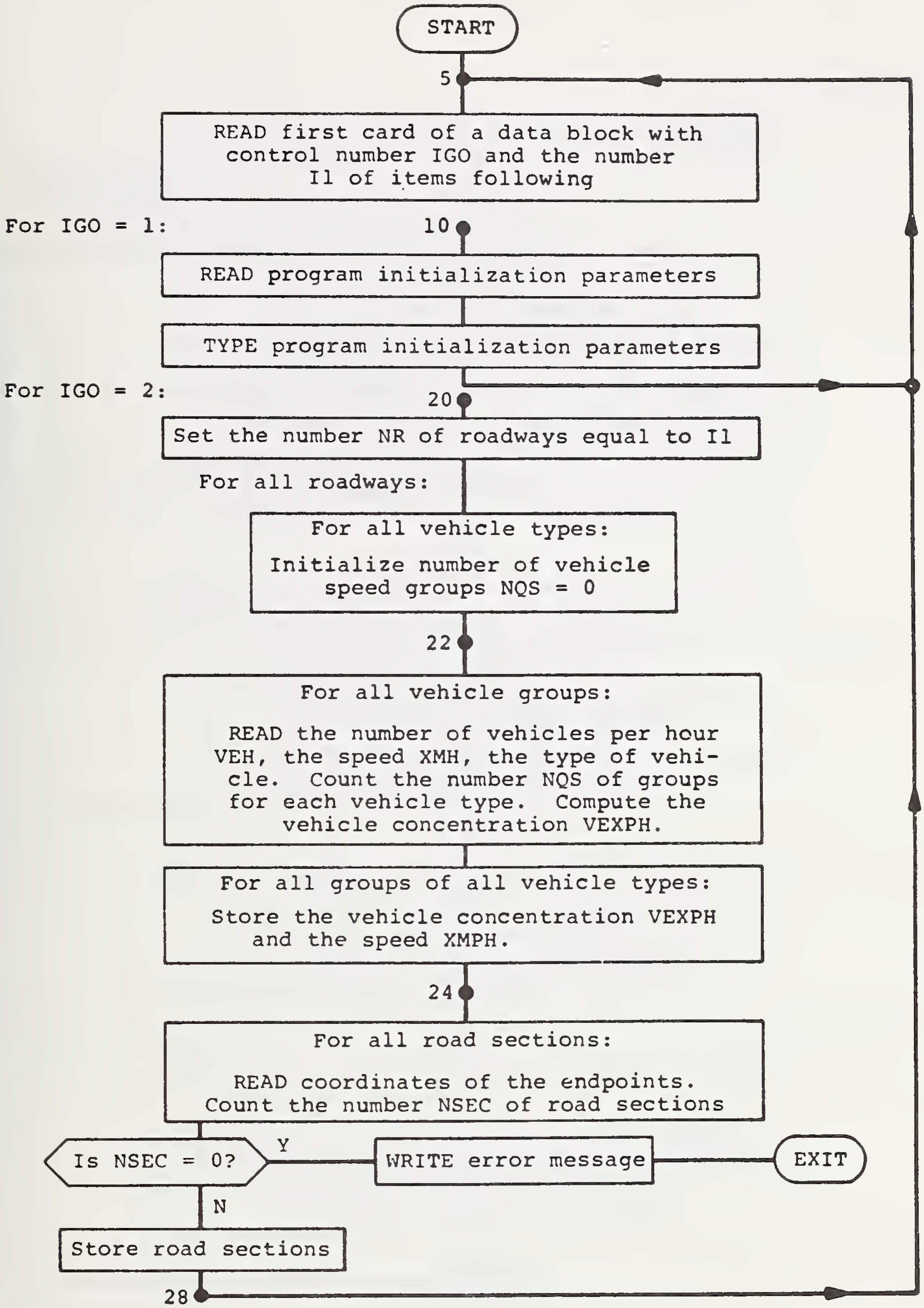


FIGURE E-1. SUBROUTINE INPUT: FLOW DIAGRAM (Continued)

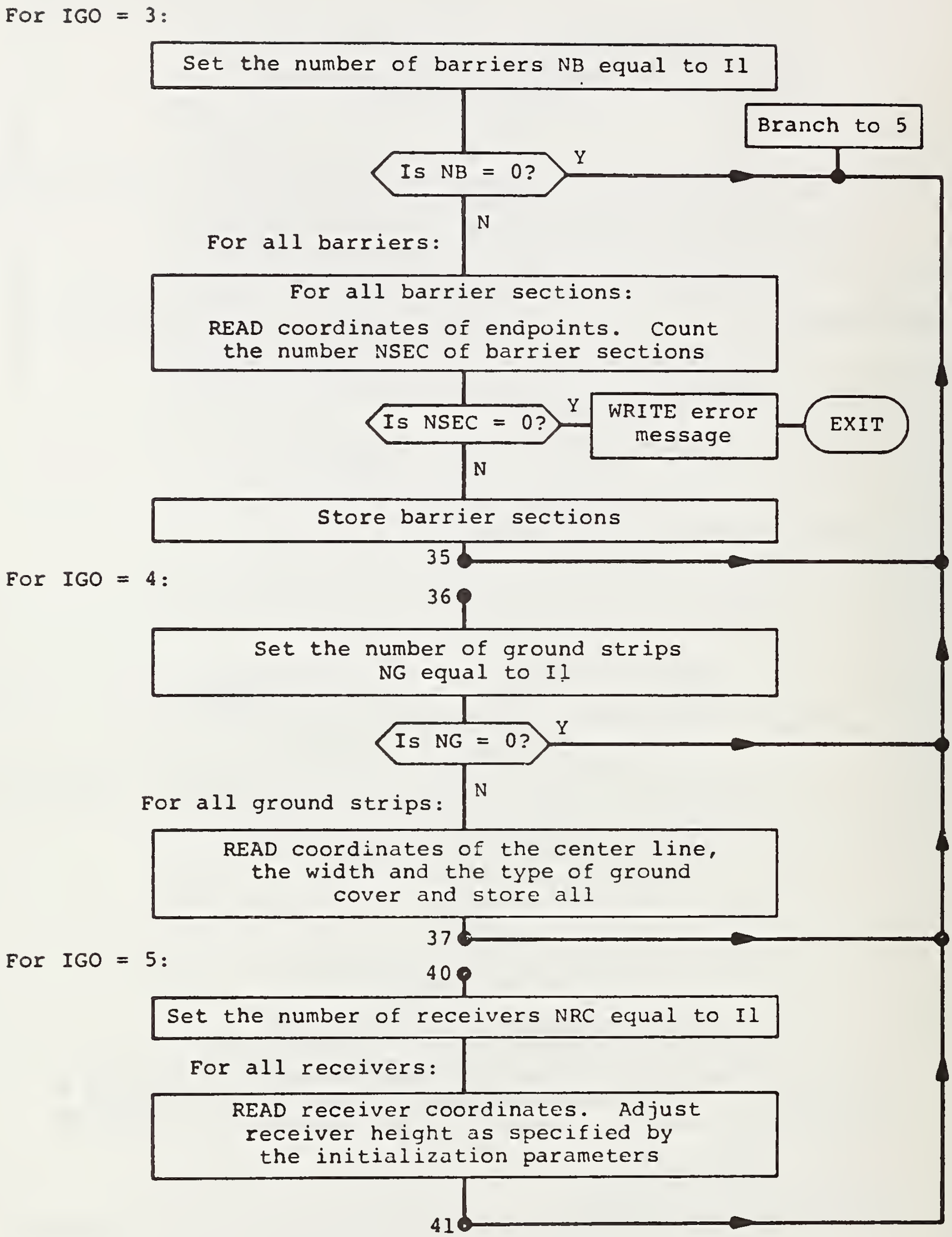


FIGURE E-1. (Continued)

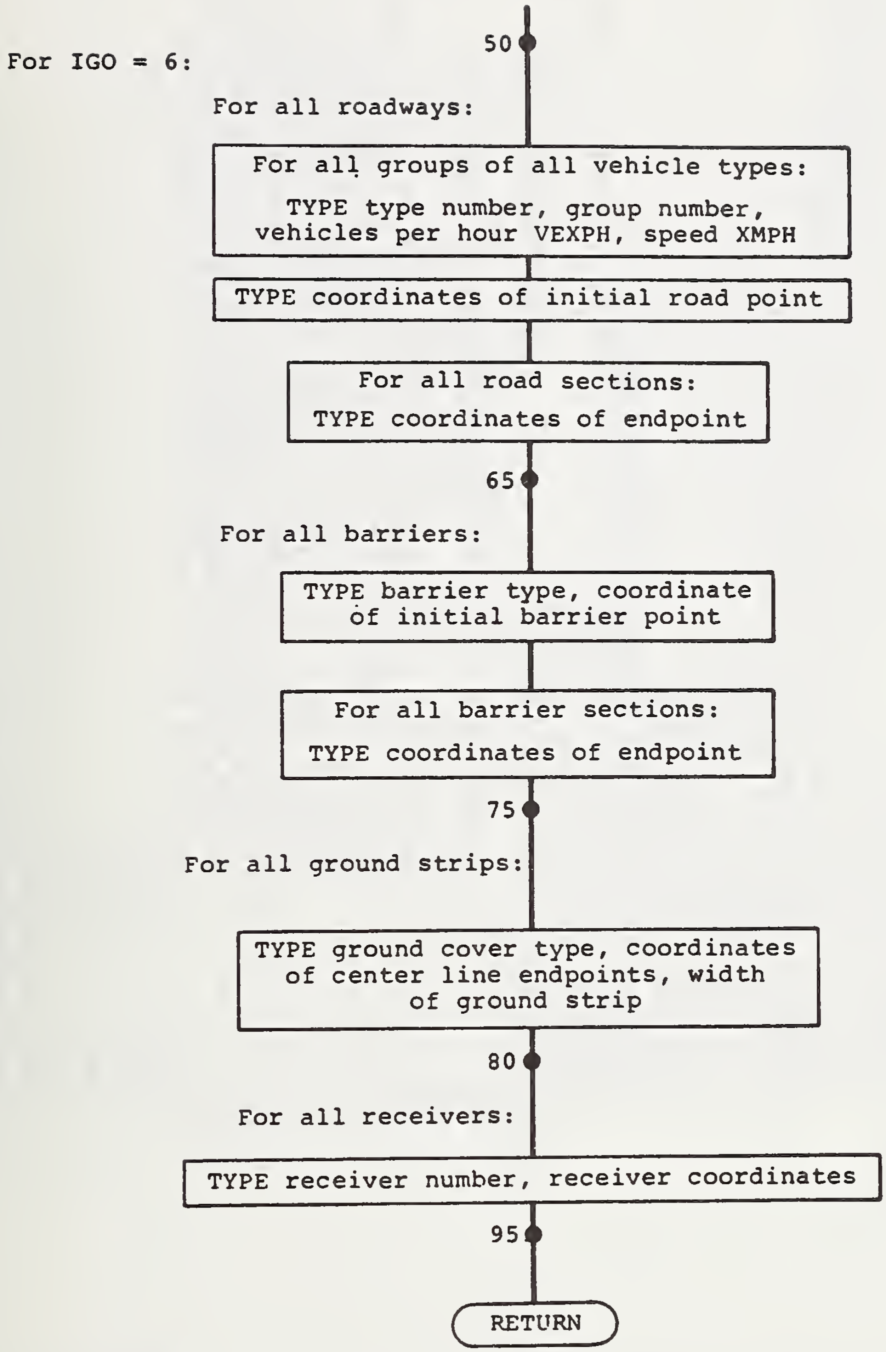


FIGURE E-1. (Concluded)

```
      SUBROUTINE INPUT
      IMPLICIT REAL*8 (A-H,O-Z)
      INTEGER ALPHA(25),ALPI(14,6),BLNK
      COMMON/DRIV2/NQS(20,4),NF
      DIMENSION VTEMP(5)
      COMMON/STORE1/BX(20,11),BY(20,11),BZ(20,11),IBLAST(20),NBSM1(20)
      COMMON/STORE2/XG1(10,2),YYG1(10,2),ZZG1(10,2),BGS(10),IDJ4(10)
      COMMON/STORE3/RX(20,11),RY(20,11),RZ(20,11),NRSM1(20)
      COMMON/STORE4/XMPH(20,5,4),VEXPH(20,5,4)
      COMMON/INOU/INPT,IOUT
      COMMON/BLK2/N0
      COMMON /INPT1/RDIN(6)
      COMMON/INPT2/NR,NB,NG
      COMMON/INPT3/XRC(15),YRC(15),ZRC(15),NRC
      COMMON /CONSTS/C0(9,4),C1(9,4),C2(9,4),S0(9,4),S1(9,4),S2(9,4)
      EQUIVALENCE (RDIN(1),XNIGHT)
      DATA ALP1 /'RECE','IVER',' HEI','GHT ','ADJU','STME','NT  ',
     A           '    ','    ','    ','    ','    ','    ','    ',
     2           'NUMB','ER O','F FR','EQUE','NCY ','BAND','S   ',
     B           '    ','    ','    ','    ','    ','    ','    ',
     3           'HEIG','HT A','DJUS','TMEN','T FO','R PA','SSEN',
     C           'GER ','CARS',' (TY','PE 1',' VEH','ICLE','S)  ',
     4           'HEIG','HT A','DJUS','TMEN','T FO','R HE','AVY ',
     D           'TRUC','KS  ',' (TY','PE 2',' VEH','ICLE','S)  ',
     5           'HEIG','HT A','DJUS','TMEN','T FO','R ME','DIUM',
     E           ' TRU','CKS ',' (TY','PE 3',' VEH','ICLE','S)  ',
     6           'HEIG','HT A','DJUS','TMEN','T FO','R NE','W VE',
     F           'HICL','ES  ',' (TY','PE 4',' VEH','ICLE','S)  '/
      DATA   IA/2HA /
      DATA   IG/2HG /
      DATA   IR/2HR /
      DATA   IT/2HT /
      DATA LAST/2HL /
      DATA BLNK/2H  /
```

SUBROUTINE INPUT: LISTING (Continued)

```
    5 READ(INPT,1000)IGO,I1,I2
      GO TO(10,20,30,36,40,50),IGO
C GARBAGE DATA....PROGRAM INITIALIZATION PARAMETERS
   10 WRITE(IOUT,2000)
      NO4 = 0
      DO 12 I=1,6
 12   RDIN(I) = 0.0
   11 READ(INPT,1001) VALUE,IDN,ILAST,(ALPHA(I),I=1,25)
      RDIN(IDN)=VALUE
      IF (IDN.EQ.6) NQ4=1
      DO 7 I=1,25
      IF(ALPHA(I).NE.BLNK) GO TO 13
    7 CONTINUE
      WRITE(IOUT,2016) VALUE,IDN,(ALPI(I,IDN),I=1,14)
      GO TO 14
   13 WRITE(IOUT,2001) VALUE,IDN,(ALPHA(I),I=1,25)
   14 IF(ILAST.NE.LAST) GO TO 11
      IF (NQ4.EQ.0) GO TO 5
      NQ = 4
      READ(INPT,1006) (CO(I,4),I=1,9),(SO(I,4),I=1,9)
C    1                ,(C1(I,4),I=1,9),(S1(I,4),I=1,9)
C    2                ,(C2(I,4),I=1,9),(S2(I,4),I=1,9)
      WRITE(IOUT,2015) (CO(I,4),I=1,9),(SO(I,4),I=1,9)
C    1                 ,(C1(I,4),I=1,9),(S1(I,4),I=1,9)
C    2                 ,(C2(I,4),I=1,9),(S2(I,4),I=1,9)
      GO TO 5
C
C
C VEHICLE DATA
C
   20 NR=11
      DO 28 J=1,NR
      NSEC=1
      DO 21 K=1,NQ
   21 NQS(J,K)=0
   22 READ(INPT,1002) VEH,XMH,ITY,ILAST
      IF (XMH.GE.20.) GO TO 23
```

SUBROUTINE INPUT: LISTING (Continued)

```
      XMH=20.
      WRITE(IOUT,2020)
       GO TO 230
 23   IF (XMH.LE.70.) GO TO 230
      XMH=70.
      WRITE(IOUT,2030)
 230  NQS(J,ITY)=NQS(J,ITY)+1
      NQC1=NQS(J,ITY)
      VEXPH(J,NQC1,ITY)=VEH/XMH/5280.
      XMPH(J,NQC1,ITY)=XMH
      IF(ILAST.NE.LAST)GO TO 22
C ROADWAY DATA SECTIONS
   24 READ(INPT,1003)RX(J,NSEC),RY(J,NSEC),RZ(J,NSEC),ILAST
      IF(ILAST EQ.LAST)GO TO 25
      NSEC=NSEC+1
      GO TO 24
   25 IF(NSEC-1.NE.0)GO TO 26
      WRITE(IOUT,2010)
      CALL EXIT
   26 NRSM1(J)=NSEC-1
   28 CONTINUE
      GO TO 5
C BARRIER DATA SECTIONS
   30 NB=I1
      IF(NB.EQ.0)GO TO 5
      DO 35 J=1,NB
      NSEC=1
   31 READ(INPT,1003)BX(J,NSEC),BY(J,NSEC),BZ(J,NSEC),IBLAST(J)
      IF(IBLAST(J).EQ.IA.OR.IBLAST(J).EQ.IR)GO TO 32
      NSEC=NSEC+1
      GO TO 31
   32 IF(NSEC-1.NE.0)GO TO 33
      WRITE(IOUT,2011)
      CALL EXIT
   33 NBSM1(J)=NSEC-1
   35 CONTINUE
      GO TO 5
C ABSORBING GROUND STRIPS
   36 NG=I1
```

SUBROUTINE INPUT: LISTING (Continued)

```
      IF(NG.EQ.0)GO TO 5
      DO 37 I=1,NG
      READ(INPT,1004)XXG1(I,1),YYG1(I,1),ZZG1(I,1),3GS(I)
      READ(INPT,1003)XXG1(I,2),YYG1(I,2),ZZG1(I,2),IDUM(I)
      IF(IDUM(I).EQ.IG)IDUM(I)=1
      IF(IDUM(I).EQ IT)IDUM(I)=2
   37 CONTINUE
      GO TO 5
C RECEIVER DATA
   40 NRC=II
      DO 41 I=1,NRC
      READ(INPT,1003)XRC(I),YRC(I),ZRC(I),IRDUM
      ZRC(I)=ZRC(I)+XNIGHT
   41 CONTINUE
      GO TO 5
C
   50 DO 65 J=1,NR
      WRITE(IOUT,2002)J
      DO 55 K=1,NQ
      NQC1=NQS(J,K)
      IF(NQC1.EQ.0) GO TO 55
      DO 54 I=1,NQC1
   54 VTEMP(I)=VEXPH(J,I,K)*XMPH(J,I,K)*5280.
      WRITE(IOUT,2004)K,(I,VTEMP(I),XMPH(J,I,K),I=1,NQC1)
   55 CONTINUE
      WRITE(IOUT,2013)
      WRITE(IOUT,2005)RX(J,1),RY(J,1),RZ(J,1)
      NSEC=NRSM1(J)+1
      DO 60 I=2,NSEC
      WRITE(IOUT,2006)I,RX(J,I),RY(J,I),RZ(J,I)
   60 CONTINUE
   65 CONTINUE
      IF(NB.EQ.0)GO TO 80
      DO 75 J=1,NB
      WRITE(IOUT,2007)J,IBLAST(J)
```

SUBROUTINE INPUT: LISTING (Continued)

```
      WRITE(IOUT,2005)BX(J,1),BY(J,1),BZ(J,1)
      NSEC=NBSM1(J)+1
      DO 70 I=2,NSEC
      WRITE(IOUT,2006)I,BX(J,I),BY(J,I),BZ(J,I)
   70 CONTINUE
   75 CONTINUE
   80 IF(NG.EQ.0) GO TO 90
      DO 85 I=1,NG
      IF(IDUM(I).EQ.1)IDM=IG
      IF(IDUM(I).EQ.2)IDM=IT
      WRITE(IOUT,2012)I,IDM,XXG1(I,1),YYG1(I,1),ZZG1(I,1),
     1 BGS(I),XXG1(I,2),YYG1(I,2),ZZG1(I,2)
   85 CONTINUE
   90 WRITE(IOUT,2008)
      DO 95 I=1,NRC
      WRITE(IOUT,2006)I,XRC(I),YRC(I),ZRC(I)
   95 CONTINUE
      RETURN
 1000 FORMAT(3I5)
 1001 FORMAT(E10.0,I5,4X,A1,10X,25A2)
 1002 FORMAT(2E10.0,I5,5X,A1)
 1003 FORMAT(3E10.0,A1)
 1004 FORMAT(4E10.0)
 1006 FORMAT(9E5.0)
 2000 FORMAT(34H PROGRAM INITIALIZATION PARAMETERS)
 2001 FORMAT(1X,E12.5,I10,5X,25A2)
 2002 FORMAT(10H ROADWAY  ,I3)
 2004 FORMAT(10H NUMBER OF13X,5HVEH/H8X,3HMPH/5H TYPE,I2,4H VEH/(3X,I2
     1,15X,2E13.4))
 2005 FORMAT(7H NUMBER,5X,1HX12X,1HY12X,1HZ/4X,1H1,2X,3E13.4)
 2006 FORMAT(3X,I2,2X,3E13.4)
 2007 FORMAT(10H BARRIER  I3,2X,1H(A1,1H)10X,19HBARRIER COORD IN FT)
 2008 FORMAT(9H RECEIVER14X,20HRECEIVER COORD IN FT/7H NUMBER5X,1HX12X,1
     1HY12X,1HZ)
 2010 FORMAT(27H INSUFFICIENT ROAD SECTIONS)
```

SUBROUTINE INPUT: LISTING (Continued)

```
0151      2011  FORMAT(31H INSUFFICIENT BARRIER SECTIONS)
0152      2012  FORMAT(18H ABSORBING STRIP  I3,2X,1H(A1,1H)//5H PT  7X,1HX12X,1HY1
               A2X,1HZ12X,5HWIDTH/4X,1H12X,4E13.4/4X,1H22X,3E13.4)
0153      2013  FORMAT(22X,18HSOURCE COORD IN FT)
0154      2015  FORMAT(5X,23HOPTIONAL NOISE SPECTRUM,
               X       (/5X,'CONSTANTS :',9F7.1/5X,'STD. DEV. :',9F7.1))
0155      2016  FORMAT(1X,E12.5,I10,5X,14A4)
0156      2022  FORMAT('0VEHICLE SPEED SUPPLIED IS LESS THAN 20 MPH. ADJUSTED TO 2
               1 0.')
0157      2023  FORMAT('0VEHICLE SPEED SUPPLIED IS GREATER THAN 70 MPH. ADJUSTED T
               1O 70.')
0158            END
```

SUBROUTINE INPUT: LISTING (Concluded)

E.2 SUBROUTINE CHECK (IERR)

PURPOSE: To check for intersection of roadways and barriers or ground strips. If intersection exists, the program would return with an error code and execution would be terminated.

SUBPROGRAMS USED:

KCUT (X1, X2, X3, X4)
INTCPT (X1, X2, X3, X4, X5)
KPOS (X1, X2, X3)

VARIABLES:

Input Parameters

NR - Number of roadways
NRSM1(NR) - Number of roadway segments in each roadway
RX(M,N), RY(M,N) - X,Y coordinates of roadway segments
NB - Number of barriers
NBSM1(NB) - Number of segments in each barrier
BX(IBAR,ISEG), BY(IBAR,ISEG) - X,Y Coordinates of barrier segments
NG - Number of ground strips
XXG1(IGRA,I), XXG2(IGRA,I) - X,Y coordinates of ground strips

Subroutine Parameters

XR1(I) - Point 1 of roadway segment
XR2(I) - Point 2 of roadway segment
XB1(I) - Point 1 of barrier segment
XB2(I) - Point 2 of barrier segment
XG1(I) - Point 1 of ground strip
XG2(I) - Point 2 of ground strip

Output Parameters

IERR - Error code

IERR = 1, if barrier intersects roadway
= 2, if ground strip intersects roadway

SUBROUTINE CHECK (Continued)

RESTRICTION: None

SIZE: 1404_8

REFERENCE: None

```
      SUBROUTINE CHECK(IERR)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/INOU/INPT,IOUT
      COMMON/STORE1/BX(20,11),BY(20,11),BZ(20,11),IBLAST(20),NBSM1(20)
      COMMON/STORE2/XXG1(10,2),YYG1(10,2),ZZG1(10,2),BGS(10),IDUM(10)
      COMMON/STORE3/RX(20,11),RY(20,11),RZ(20,11),NRSM1(20)
      COMMON/INPT2/NR,NB,NG
      DIMENSION XR1(2),XR2(2)
      DIMENSION XB1(2),XB2(2),XG1(2),XG2(2)
      IERR=0
      DO 40 M=1,NR
      XR1(1) = RX(M,1)
      XR1(2) = RY(M,1)
      NLIM = NRSM1(M) + 1
      DO 40 N=2,NLIM
      XR2(1) = RX(M,N)
      XR2(2) = RY(M,N)
      IF (NB EQ.0) GO TO 20
      DO 10 IBAR=1,NB
      XB1(1) = BX(IBAR,1)
      XB1(2) = BY(IBAR,1)
      NLIM = NBSM1(IBAR) + 1
      DO 10 ISEG=2,NLIM
      XB2(1) = BX(IBAR,ISEG)
      XB2(2) = BY(IBAR,ISEG)
      IF (KCUT(XR1,XR2,XB1,XB2).EQ.1) GO TO 80
   10 CONTINUE
   20 IF (NG.EQ.0) GO TO 40
      DO 30 IGRA=1,NG
      XG1(1) = XXG1(IGRA,1)
      XG1(2) = YYG1(IGRA,1)
      XG2(1) = XXG1(IGRA,2)
      XG2(2) = YYG1(IGRA,2)
      IF (KCUT(XR1,XR2,XG1,XG2).EQ.1) GO TO 90
   30 CONTINUE
```

SUBROUTINE CHECK: LISTING (Continued)

```
 40   CONTINUE
      RETURN
 80   IERR=1
      WRITE(IOUT,1006)M,N,IBAR,ISEG
      RETURN
 90   IERR=2
      WRITE(IOUT,1008)M,N,IGRA
      RETURN
1006  FORMAT('0ILLEGAL BARRIER INTERSECTS ROADWAY',5X,'R ',I2,2X
     1,3HRS I2,2X,2HB I2,2X,3HBS I2)
1008  FORMAT('0ILLEGAL GROUND STRIP INTERSECTS ROADWAY',5X,I2,2X,2
     1HR I2,3HRS I2,2X,4HAGS I2)
      END
```

SUBROUTINE CHECK: LISTING (Concluded)

E.3 SUBROUTINE INTER (NR, IQ)

PURPOSE: To determine, by interpolation, vehicle emission and corresponding standard deviation, given a certain roadway, vehicle type and speed.

SUBPROGRAMS USED: BLOCK DATA (Transferred through COMMON/CONSTS/)

VARIABLES: Input Parameters

NR - Roadway number

IQ - Vehicle type number

CO(NF,NQ), C1(NF,NQ), C2(NF,NQ) - Constants obtained by non-linear regression, using the following equation:

L(V) = CO(IF,IQ) + C1(IF,IQ) * V
+ C2(IF,IQ) *V**2

where

V = speed at 25, 35, 45, 55 & 65 mph

L(V) = sound level at V

SO(NF,NQ), S1(NF,NQ), S2(NF,NQ) - Standard deviations corresponding to CO, C1 and C2. Obtained by similar method as above.

NQS(NR,IQ) - Number of traffic flow conditions

XMPH - Speed at which interpolation is done

Subroutine Parameters

V - Same as XMPH(NR,IQ)

INDEX - Position in arrays where the calculated emission level and the corresponding standard deviation are stored

MULT - Factor to be multiplied to obtain INDEX

SIGL1 - Interpolated value of reference standard deviation and

XLREF - Interpolated value of reference sound level.

SUBROUTINE INTER (NR, IQ) (Continued)

Output Parameters

XLREF(INDEX)- Value of reference acoustic intensity

CQ(INDEX) - Value of reference standard deviation factor

RESTRICTION: The constants for vehicle types 1 - 3 and their standard deviations are provided in the program. If a new type of vehicle is introduced, its corresponding constants and standard deviations must be read in from cards. See Subroutine INPUT.

REFERENCES: None

SIZE: 1080_8

```
C   SUBROUTINES FOR TRAFFIC NOISE   12/76   SAI MOD
      SUBROUTINE INTER(NR,IQ)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /CONSTS/C0(9,4),C1(9,4),C2(9,4),S0(9,4),S1(9,4),S2(9,4)
      COMMON/STORE4/XMPH(20,5,4),VEXPH(20,5,4)
      COMMON/DRIV2/NQS(20,4),NF
      COMMON /INTER1/XLREF(3600),CQ(3600)
      DO 10 IF=1,NF
      CC0 = C0(IF,IQ)
      CC1 = C1(IF,IQ)
      CC2 = C2(IF,IQ)
      SS0 = S0(IF,IQ)
      SS1 = S1(IF,IQ)
      SS2 = S2(IF,IQ)
      MULT = 5 * ((IF-1) + 9*(IQ-1))
      NQQ = NQS(NR,IQ)
      DO 10 I=1,NQQ
      V = XMPH(NR,I,IQ)
      INDEX = NR + 20*((I-1)+MULT)
      SIGL1 = SS0 + SS1*V + SS2*V**2
      IF (IQ.EQ.1) GO TO 5
      XLREF1 = CC0 + CC1*V + CC2*V**2
      GO TO 7
    5 XLREF1 = CC0 + CC1*DLOG10(V)
    7 XLREF(INDEX) = 10. ** ((XLREF1-66.)/10.)
      CQ(INDEX) = DEXP(0.5*(SIGL1*0.23026)**2)
   10 CONTINUE
      RETURN
      END
```

SUBROUTINE INTER: LISTING

E.4 SUBROUTINE BLOCK DATA

PURPOSE: To provide a data block of coefficients for the interpolation polynomials used by subroutine INTER in calculating the vehicle noise emission characteristics.

SUBPROGRAMS USED: None

VARIABLES:

CO(NF,NQ) - Constant terms in the vehicle sound level interpolation polynomial for the frequency bands NF and vehicle type NQ

C1(NF,NQ) - Coefficients of the linear term in the vehicle sound level interpolation polynomial

C2(NF,NQ) - Coefficients of the quadratic term in the vehicle sound level interpolation polynomial

SO(NF,NQ) - Constant terms in the vehicle sound level standard deviation interpolation polynomial for the frequency band NF and the vehicle type NQ

S1(NF,NQ) - Coefficients of the linear term in the vehicle sound level standard deviation interpolation polynomial

S2(NF,NQ) - Coefficients of the quadratic term in the vehicle sound level standard deviation interpolation polynomial

INPT - Constant specifying the input device to by used by the prediction code (5 denotes a card reader)

IOUT - Constant specifying the output device to be used by the prediction code (6 denotes a line printer).

RESTRICTIONS: The constants CO(NF,NQ),..., S2(NF,NQ) are stored as follows:

CO(1,1), CO(2,1),...CO(9,1); CO(1,2),...,C)(9,2); CO(1,3),...,CO(9,3); etc.

The user should note that all constants relating to the type 4 vehicle (NQ=4) are set to zero unless they are defined by the user upon input.

SIZE: 0_8

REFERENCES: See Section A.2 of Appendix A, Subroutine INTER and Subroutine INPUT.

```
0001    BLOCK DATA
0002    IMPLICIT REAL*8 (A-H,O-Z)
0003    COMMON /CONSTS/C0(9,4),C1(9,4),C2(9,4),S0(9,4),S1(9,4),S2(9,4)
0004    COMMON/INOU/INPT,IOUT
0005    DATA INPT/5/,IOUT/6/
0006    DATA C0/4.80,-2.14,-3.17,-13.21,10.84,9.83,-13.25,-7.20,-18.21,
       2 60.637,47.983,56.170,38.488,49.917,53.646,62.356,60.4879,42.855,
       3 42.691,45.075,49.971,42.650,29.336,22.981,18.863,32.410,38.208,
       4 9*0.0/
0007    DATA C1/38.05,27.18,32.61,40.76,29.39,32.51,43.92,33.05,40.75,
       2 0.8254,0.7786,0.4660,1.4491,0.9669,0.8851,0.4471,0.3546,0.7760,
       3 1.321,0.4574,0.6837,1.112,1.5483,1.8671,1.9331,1.1546,0.7091,
       4 9*0.0/
0008    DATA C2/9*0.0,
       2 -.00657,-.00948,-.004,-.0134,-.00764,-.00686,-.00286,-.00243,
       A -.0070,
       3 -.0109,-.00407,-.00679,-.01,-.0127,-.0159,-.0164,-.00893,-.00536,
       4 9*0.0/
0009    DATA S0/9*2.5,
       2 9.0293,-.3846,5.8529,0.1839,2.9979,10.8732,10.87,14.3864,5.1886,
       3 -3.3164,3.9004,7.6146,-3.8543,-6.6989,-7.3718,-10.3568,-.3814,
       A -.7321,
       4 9*0.0/
0010    DATA S1/9*0.0,
       2 -.2151,.3206,-.0694,.2023,.0426,-.2269,-.252,-.3817,-.00429,
       3 .3077,.0686,-.0546,.4311,.4677,.5171,.6231,.2077,.2226,
       4 9*0.0/
0011    DATA S2/9*0.0,
       2 .00186,-.00393,.000571,-.00221,-.000429,.00164,.002,.00329,
       A -.000286,
       3 -.00329,-.000929,-.0000714,-.00486,-.00479,-.00536,-.00515,
       B -.00229,-.00243,
       4 9*0.0/
0012    END
```

SUBROUTINE BLOCK DATA: LISTING

PURPOSE: The subroutine checks to see if the point X3V is colinear with the points X1V, X2V in the x-y plane. The x-y coordinates of the point X3V are altered by the subroutine so that the point X3V is not colinear with points X1V, X2V, if the points are judged to be collinear.

SUBPROGRAMS USED: IAREA (X1V, X2V, X3V), ANGLE (X1V, X2V, X3V)

VARIABLES: Input Parameters

X1V(I), X2V(I), X3V(I) - Three points in the x-y plane defined by their components.

x - component I = 1

y - component I = 2

Subprogram Parameters

ANG - The angle between the line segments (X1V,X3V) and (X2V, X3V).

Output Parameters

X3V(I) - The components of a point in the x-y plane, X3V(I),that is near to the input values X3V(I) but that is not considered by the routine to be colinear with the points X1V, X2V. (See RESTRICTIONS).

RESTRICTIONS: The criteria used to judge whether or not X3V is colinear with X1V, X2V is the area of the triangle formed by the points X1V, X2V, X3V and, possibly, the magnitude of the variable ANG.

SUBROUTINE COLIN (X1V, X2V, X3V) Concluded

ACCURACY: That of the criteria.

SIZE: 738_8

REFERENCES: See Subprograms IAREA and ANGLE.

```
      SUBROUTINE COLIN(X1V,X2V,X3V)
C CHECK WHETHER RECEIVER IS CO-LINEAR WITH ROADWAY SEGMENT
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(2),X2V(2),X3V(2)
      IF(IAREA(X1V,X2V,X3V).EQ.0) GO TO 10
    5 ANG=ANGLE(X1V,X2V,X3V)
      IF(ANG.GE.2.6E-5) RETURN
   10 X3V(1)=X3V(1)+1.0
      IF(IAREA(X1V,X2V,X3V).EQ.0) GO TO 20
      ANG=ANGLE(X1V,X2V,X3V)
      IF(ANG.GE.2.6E-5) RETURN
   20 X3V(2)=X3V(2)+1.0
      IF(IAREA(X1V,X2V,X3V).EQ.0) GO TO 5
      RETURN
      END
```

SUBROUTINE COLIN: LISTING

E.6 SUBROUTINE DEGEN (X1V, X2V, X3V, X4V, X5V, LOC)

PURPOSE: This subroutine preprocesses data for subroutine BLOCN to ensure that degenerate geometrical alignments between the points X1V, X2V, X3V and a line segment X4V, X5V that may confuse the logic of subroutine BLOCN do not occur. Physically, the line segment defined by the x(I=1) and y(I=2) coordinates of the points X1V(I) and and X2V(I) represents a road segment, the point X3V(I) represents a receiver, and the line segment defined by the points X4V(I) and X5V(I) represent either a barrier or an absorption ground strip.

THIS SUBROUTINE SHOULD BE USED ONLY AS A PREPROCESSOR FOR SUBROUTINE BLOCN.

SUBPROGRAMS USED: IAREA (X1V, X2V, X3V), MOVE2 (X1V, X2V, X3V, DELTA, IERR)

VARIABLES: Input Parameters

X1V(I), X2V(I) - Points defining a road segment location in the x(I=1), y(I=2) plane.

X3V(I) - A point defining the receiver location in the x(I=1), y(I=2) plane.

X4V(I), X5V(I) - Points defining a barrier or ground strip location in the x,y plane. See Output Parameters.

Output Parameters

LOC A logic parameter indicating the relative alignment of the line segment (X4V, X5V) with the line segments (X1V, X3V) and (X2V, X3V). LOC = 0 or 3 or 5.

LOC = 0 indicates that neither point X4V nor point X5V is colinear with the line segments (X1V, X3V) or (X2V, X3V).

LOC = 3 indicates that point X4V is colinear with (X1V, X3V) and that point X5V is colinear with (X2V, X3V) or that point X4V is colinear with (X2V, X3V) and that point X5V is colinear with (X1V, X3V). That is, the line segment (X4V, X5V) exactly blocks the (x, y) plane line-of-sight from the receiver X3V to the roadway (X1V, X2V).

LOC = 5 indicates that either point X4V or X5V was determined to be colinear with one of the segments (X1V, X3V) or (X2V, X3V) or neither point X4V or X5V was colinear with one of the segments (X1V, X3V) or (X2V, X3V). If either X4V or X5V was determined to be colinear, the point is relocated by subroutine MOVE2 increasing the length of the segment (X4V, X5V) by 1 foot.

X4V(I), X5V(I) - If LOC = 5, either X4V(I) or X5V(I) may be relocated as indicated above so that X4V(I) or X5V(I) is not collinear with the segments (X1V, X3V) or (X2V, X3V).

RESTRICTIONS: This subroutine should be used only as a preprocessor for subroutine BLOCN. See listing of subroutine GEOMRY for usage.

If an error occurs in subroutine MOVE2, the following message is printed: "ERROR IN MOVE2". This error will

SUBROUTINE DEGEN (X1V, X2V, X3V, X4V, X5V, LOC) Concluded

not be, quite likely, fatal but the user should check results closely.

ACCURACY: See RESTRICTIONS.

SIZE: 1684_8

REFERENCES: None.

SUBROUTINE DEGEN: LISTING

```
      SUBROUTINE DEGEN(X1V,X2V,X3V,X4V,X5V,LOC)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/INOU/INPT,IOUT
      DIMENSION X1V(2),X2V(2),X3V(2),X4V(2),X5V(2)
      LOC=5
      IF(IAREA(X4V,X1V,X3V).EQ.0) GO TO 10
      IF(IAREA(X4V,X2V,X3V).EQ.0) GO TO 40
      IF(IAREA(X5V,X1V,X3V).EQ.0) GO TO 45
      IF(IAREA(X5V,X2V,X3V).EQ.0) GO TO 45
      RETURN
   10 IAREA1=IAREA(X5V,X2V,X3V)
      IF(IAREA1.EQ.0) GO TO 30
      IAREA2=IAREA(X5V,X3V,X1V)
      IAREA3=IAREA(X5V,X1V,X2V)
      IF(IAREA1.EQ.IAREA2.AND.IAREA1.EQ.IAREA3) GO TO 55
   20 LOC=0
      RETURN
   30 LOC=3
      RETURN
   40 IAREA1=IAREA(X5V,X3V,X1V)
      IF(IAREA1.EQ.0) GO TO 30
      IAREA2=IAREA(X5V,X1V,X2V)
      IAREA3=IAREA(X5V,X2V,X3V)
      IF(IAREA1.EQ.IAREA2.AND.IAREA1.EQ.IAREA3) GO TO 55
      GO TO 20
   45 IAREA1=IAREA(X4V,X3V,X1V)
      IAREA2=IAREA(X4V,X1V,X2V)
      IAREA3=IAREA(X4V,X2V,X3V)
      IF(IAREA1.EQ.IAREA2.AND.IAREA1.EQ.IAREA3) GO TO 60
      GO TO 20
   55 CALL MOVE2(X4V,X4V,X5V,1.0,IERR)
      IF(IERR.EQ.4) WRITE(IOUT,1000)
      RETURN
   60 CALL MOVE2(X5V,X5V,X4V,1.0,IERR)
      IF(IERR.EQ.4) WRITE(IOUT,1000)
      RETURN
 1000 FORMAT(1H ,14HERROR IN MOVE2)
      END
```

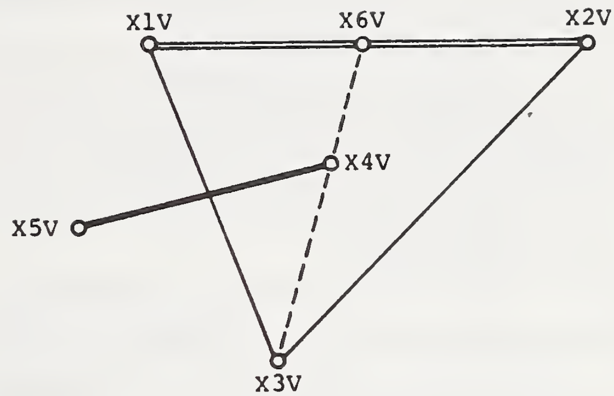
PURPOSE: This subroutine calculates the alignments in the x-y plane, of one line segment relative to the alignment of another line segment and a point. Physically, the line segment defined by the x(I = 1), y(I = 2) coordinates of the points X1V(I) and X2V(I) represents a road segment, the point X3V(I) represents a receiver, and the line segment defined by the points X4V(I) and X5V(I) represent either a barrier or an absorptive ground strip.

The subroutine output is a point X6V(I) in the x-y plane and a configuration index, LOC. See Figure E-2.
If LOC = 0, the line segment defined by X4V, X5V is outside the triangle formed by X1V, X2V, X3V. In this case, the subroutine assigns no values to X6V.

If LOC = 1, this line segment defined by X4V, X5V intersects the line segment defined by X1V, X3V. In this case, the subroutine assigns X6V as the intersection point (in the x-y plane) of the line segment X1V, X2V and the line defined by the points X3V, X4V or X3V, X5V.

If LOC =2, the line segment defined by X4V, X5V intersects the line segment defined by X2V, X3V. In this case, the subroutine assigns X6V as the intersection point (in the x-y plane) of the line segment X1V, X2V and the line defined by the points X3V, X4V or X3V, X5V.

If LOC = 3, the line segment defined by X4V, X5V intersects both line segments defined by X1V, X3V and X2V, X3V (ie, the road segment, as viewed from point X3V, is completely covered by the line segment X4V, X5V). In this case, the subroutine assigns no values to X6V.



LOC = 0 denotes that the line X4V, X5V is outside the triangle X1V, X2V, X3V.

LOC = 1 denotes that the line X4V, X5V intersects the line X1V, X3V.

LOC = 2 denotes that the line X4V, X5V intersects the line X2V, X3V.

LOC = 3 denotes that the line X4V, X5V intersects both lines X1V, X3V and X2V, X3V.

LOC = 4 denotes that the line X4V, X5V is completely inside the triangle X1V, X2V, X3V.

FIGURE E-2. SUBROUTINE BLOCN: RELATIVE GEOMETRY

SUBROUTINE BLOCN (X1V, X2V, X3V, X4V, X5V, X6V, LOC) Continued

If LOC = 4, the line segment defined by X4V, X5V is interior to the triangle defined by the points X1V, X2V, X3V. In this case, the subroutine assigns X6V as the intersection point on the line segment X1V, X2V of the line from X3V to either X4V or X5V that is closest to the point X1V. <u>SEE RESTRICTIONS</u>

SUBPROGRAMS USED: KCUT(X1, X2, X3, X4), TRI(X1, X2, X3, X4, X5, KTRI) INTCPT(X1, X2, X3, X4, X5), <u>SEE RESTRICTIONS</u>, <u>SEE SUBROUTINE DEGEN</u>

VARIABLES: <u>Input parameters</u>

X1V(I), X2V(I) - points defining a road segment location in the x(I=1), y(I=2) plane.

X3V(I) - a point defining the receiver location in the x(I = 1), y(I = 2) plane.

X4V(I), X5V(I) - points defining a line segment location in the x(I = 1), y(I = 2) plane.

<u>Output parameters</u>

X6V(I) - a point on the line segment defined by X1V(I), X2V(I) that represents the intersection of the line defined by either the points X3V, X4V or X3V, X5V. (SEE PURPOSE)

LOC - a parameter describing the configuration (SEE PURPOSE).

<u>Subprogram parameters</u>

KTRI - A parameter assigned by subprogram TRI.

KTRI = 0 if X4V is either exterior to the triangle X1V, X2V, X3V or lies on a line segment X1V, X2V; X1V, X3V; or X2V, X3V.

KTRI = 1 if X4V is interior to the triangle X1V, X2V, X3V.

SUBROUTINE BLOCN (X1V, X2V, X3V, X4V, X5V, X6V, LOC) Concluded

XAV(I) - a point on the line segment defined by X1V(I), X2V(I) that represents the intersection of the line defined by X3V, X4V.

XBV(I) - a point on the line segment defined by X1V(I), X2V(I) that represents the intersection of the line defined by X3V, X5V.

RESTRICTIONS: The subprogram BLOCN is used by the subprograms ENDPT and GEOMRY to establish the basic geometric relationship between a roadway segment (X1V, X2V); a receiver location, X3V; and a potentially intervening barrier or ground strip segment (X4V, X5V). Geometric configurations between the five points defined by X1V, X2V, X3V, X4V, and X5V can arise that may either produce erroneous results or program failure. To check for these potential problems and to avoid the possibility of calculating erroneous results, the subprogram DEGEN is used. The problem geometrical configurations are associated with colinearity of source-receiver points X1, X2, X3 with barrier and/or ground strip points X4V, X5V or if the points X4V and/or X5V lie on the boundary of the triangle formed by the points X1V, X2V, X3V. See Figure E-2.

ACCURACY: SEE RESTRICTIONS.

SIZE: 958_8

REFERENCES: None.

```
      SUBROUTINE BLOCN(X1V,X2V,X3V,X4V,X5V,X6V,LOC)
C FIND RELATIVE LOCATION OF BARRIER
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(2),X2V(2),X3V(2),X4V(2),X5V(2),X6V(2),XAV(2),XBV(2)
      LOC=KCUT(X1V,X3V,X4V,X5V)
      LOC=LOC+KCUT(X2V,X3V,X4V,X5V)*2
      IF(LOC.EQ.3)RETURN
      CALL TRI(X1V,X2V,X3V,X4V,XAV,KTRI)
      IF(LOC.EQ.0)GO TO 4
      IF(KTRI EQ 1)GO TO 6
    2 CALL INTCPT(X1V,X2V,X3V,X5V,XBV)
      IF(LOC.EQ.4)GO TO 5
    3 X6V(1)=XBV(1)
      X6V(2)=XBV(2)
      RETURN
    4 IF(KTRI.EQ.0)RETURN
      LOC=4
      GO TO 2
    5 IF(KPOS(X1V,XAV,XBV).EQ.1)GO TO 3
    6 X6V(1)=XAV(1)
      X6V(2)=XAV(2)
      RETURN
      END
```

SUBROUTINE BLOCN: LISTING

E.8 SUBROUTINE MOVE (X1V, X2V, X3V, DELTA, IERR) Continued

PURPOSE: To calculate the coordinates of the point X2V that lies on a line passing through the points X1V, X3V and is a specified distance, DELTA, from the point X1V in (x, y, z) coordinate space. (See VARIABLES, DELTA).

SUBPROGRAMS USED: AMAG (X1, X2)

VARIABLES:

Input Parameters

X1V(I), X3V(I) - Points in (x, y, z) coordinate space defining a line.

x - coordinate I = 1

y - coordinate I = 2

z - coordinate I = 3

DELTA - The distance from the point X1V at which one desires the point X2V to be located on the line X1V, X3V. If DELTA is positive, X2V will be located along the line defined by X1V, X3V in the direction from X3V to X1V. If DELTA is negative, X2V will be located along the line defined by X1V, X3V in the direction from X1V to X3V. If DELTA is zero, X2V will coincide with X1V.

Subprogram Parameters

TEMP - The length of the line segment defined by the points X1V, X3V.

FCTR - The ratio of DELTA to TEMP

Output Parameters

X2V(I) - The x, y, z coordinates of the point X2V.

SUBROUTINE MOVE (X1V, X2V, X3V, DELTA, IERR) Concluded

IERR - An error indicator. If TEMP is greater than zero (i.e., X1V and X3V do not coincide) then IERR = 0. If TEMP is equal to zero (i.e., X1V and X3V coincide) then IERR = 4 and the point X2V(I) is not calculated when control is returned to the calling program.

RESTRICTIONS: See description of variable IERR.

ACCURACY: Not applicable.

SIZE: 582_8

REFERENCES: The point X2V is calculated using the vector relation

$$\vec{R}_2 = \vec{R}_1 + \text{DELTA}\ \vec{r}_{31}$$

$$\vec{r}_{31} = \vec{R}_{31} / \sqrt{\vec{R}_{31} \cdot \vec{R}_{31}}$$

```
      SUBROUTINE MOVE(X1V,X2V,X3V,DELTA,IERR)
C MOVE ENDPOINT OF ROAD
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(3),X2V(3),X3V(3)
      IERR=0
      TEMP=AMAG(X1V,X3V)
      IF(TEMP.EQ.0.) GO TO 3
      FCTR=DELTA/TEMP
      DO 2 I=1,3
      X2V(I)=X1V(I)+(X1V(I)-X3V(I))*FCTR
    2 CONTINUE
      RETURN
    3 IERR=4
      RETURN
      END
```

SUBROUTINE MOVE: LISTING

PURPOSE: To calculate, in the x-y plane, the coordinates of the point X2V that lies on a line passing through the points X1V, X3V and is a specified distance, DELTA, from the point X1V. This is the x-y plane analogue of subroutine MOVE.

SUBPROGRAMS USED: SQRT(X)

VARIABLES:

Input Parameters

X1V(I), X3V(I) - Points in the x-y plane defining a line.

x - coordinate I = 1

y - coordinate I = 2

DELTA - The distance from the point X1V at which one desires to locate the point X2V on the line defined by the points X1V, X3V. If DELTA is positive, X2V will be located on the line defined by X1V, X3V in the direction from X3V to X1V. If DELTA is negative, X2V will be located along the line defined by X1V, X3V in the direction from X1V to X3V. If DELTA is zero, X2V coincides with X1V.

Subprogram Parameters

TEMP - The length of the line segment defined by the points X1V, X3V.

FCTR - The ratio of DELTA to TEMP.

Output Parameters

X2V(I) - The x,y coordinates of the point X2V.

SUBROUTINE MOVE2 (X1V, X2V, X3V, DELTA, IERR) Concluded

IERR - An error indicator. If TEMP is greater than zero (i.e., X1V and X3V do not coincide), then IERR = 0 and the coordinates, X2V(I) are calculated. If TEMP is zero (i.e., X1V and X3V coincide), then IERR = 4 and the coordinates, X2V(I), are not calculated.

RESTRICTIONS: See description of variable IERR.

ACCURACY: Not applicable.

REFERENCES: See Subroutine MOVE.

SIZE: 596_8

```
      SUBROUTINE MOVE2(X1V,X2V,X3V,DELTA,IERR)
C MOVE AN ENDPOINT(2-DIMENSION)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(2),X2V(2),X3V(2)
      IERR=0
      TEMP=DSQRT((X1V(1)-X3V(1))**2+(X1V(2)-X3V(2))**2)
      IF(TEMP.EQ.0.0) GO TO 3
      FCTR=DELTA/TEMP
      DO 2 I=1,2
      X2V(I)=X1V(I)+(X1V(I)-X3V(I))*FCTR
    2 CONTINUE
      RETURN
    3 IERR=4
      RETURN
      END
```

SUBROUTINE MOVE2: LISTING

E.10 SUBROUTINE TRI (X1V, X2V, X3V, X4V, X5V, KTRI) Continued

PURPOSE: To calculate a logic number, KTRI, that indicates whether or not the point X4V lies within or on the boundaries of a triangle in the x-y plane formed by the points X1V, X2V, and X3V. (See VARIABLES and RESTRICTIONS).

SUBPROGRAMS USED: INTCPT (X1, X2, X3, X4, X5); KPOS (X1, X2, X3)

VARIABLES: Input Parameters

X1V(I), X2V(I), X3V(I) - The coordinates of three points in the x-y plane. The x-coordinate is denoted by I = 1; the y-coordinate by I = 2.

X4V(I) - A point in the x-y plane whose location relative to the triangle formed by the points X1V, X2V, X3V is to be determined.

Output Parameters

X5V(I) - The intersection point of the lines through X1V, X2V and X3V, X4V.

KTRI - A logic number that indicates the location of X4V relative to the triangle formed by the points X1V, X2V, X3V.

KTRI = 1 If the point X4V lies interior to or on the boundary of (excluding the point X3V) the triangle formed by the points X1V, X2V, X3V.

KTRI = 0 If the point X4V coincides with the point X3V or lies exterior to the triangle formed by the points X4V, X2V, X3V.

SUBROUTINE TRI (X1V, X2V, X3V, X4V, X5V, KTRI) Concluded

RESTRICTIONS: The intersection point X5V is always calculated and returned to the calling program. If KTRI = 1 the point X5V lies on the line segment defined by the end points X1V, X2V including the end points. If KTRI = 0 and X4V does not coincide with X3V, the point X5V lies on the line passing through the points X1V, X2V. If the points X3V and X4V coincide KTRI = 0 and X5V is projected to a point beyond $2 \cdot 10^{14}$ miles from the point X1V. (See Subprogram INTCPT). Usage of this subroutine should recognize these restrictions.

ACCURACY: That of subprograms.

SIZE: 594_8

REFERENCES: None.

```
      SUBROUTINE TRI(X1V,X2V,X3V,X4V,X5V,KTRI)
C FIND IF POINT IN TRIANGLE AND LOCATE INTERCEPT
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(2),X2V(2),X3V(2),X4V(2),X5V(2)
      CALL INTCPT(X1V,X2V,X3V,X4V,X5V)
      KTRI=0
      IF(KPOS(X1V,X2V,X5V).EQ.0)RETURN
      IF(KPOS(X3V,X5V,X4V).EQ.1)KTRI=1
      RETURN
      END
```

SUBROUTINE TRI: LISTING

E.11 SUBROUTINE INTCPT (X1V, X2V, X3V, X4V, X5V) Continued

PURPOSE: To calculate the x-y plane intersection point, X5V(I), of two lines defined by the points (X1V(I)), and (X2V(I)), and (X3V(I)), (X4V(I)). The subscript I = 1 for x-coordinates and I = 2 for y-coordinates.

SUBPROGRAMS USED: None.

VARIABLES: Input parameters

X1V(I), X2V(I) - Points in the x-y plane defining a line.

X3V(I), X4V(I) - Points in the x-y plane defining a line.

Subprogram parameters

AX, AY - x-component and y-component respectively, of the line segment defined by (X1V, X2V).

BX, BY - x-component and y-component respectively of the line segment defined by (X3V, X4V).

C1, C2 - Algebraic expressions arising in the derivation of the algorithm.

D - The value of the 2X2 determinant formed by the x,y components of the two line segments.

Output parameters

X5V(I) - The (x,y) coordinate (I = 1, I = 2, respectively) of the intersection point.

RESTRICTIONS: If either line segment has zero length, then D = 0 and a division by zero will occur. If the two line segments are parallel or coincide, D = 0 and a division by zero will occur. If $D^2 < 10^{-6}$ ft^2, the subroutine, projects the point X5V out in the x-y plane somewhere beyond a radius of 2×10^{14} miles from the point X1V. Usage should recognize these restrictions.

ACCURACY: See Restrictions.

SIZE: 738_8

SUBROUTINE INTCPT (X1V, X2V, X3V, X4V, X5V) Concluded

REFERENCES: The algorithm used to calculate the point X5V, is derived by writing the vector equation for lines passing through the points (X1V, X2V) and (X3V, X4V) and solving for their common point.

```
      SUBROUTINE INTCPT(X1V,X2V,X3V,X4V,X5V)
C FIND INTERCEPT OF TWO LINES IN A PLANE
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(2),X2V(2),X3V(2),X4V(2),X5V(2)
      AX=X2V(1)-X1V(1)
      AY=X2V(2)-X1V(2)
      BX=X4V(1)-X3V(1)
      BY=X4V(2)-X3V(2)
      C1=AY*X2V(1)-AX*X2V(2)
      C2=BY*X4V(1)-BX*X4V(2)
      D=AX*BY-AY*BX
      IF(D**2.LT.1.E-6)GO TO 2
      X5V(1)=(AX*C2-BX*C1)/D
      X5V(2)=(AY*C2-BY*C1)/D
      RETURN
    2 D=DSQRT(AX**2+AY**2)
      X5V(1)=X1V(1)+(AX/D)*1.E+15
      X5V(2)=X1V(2)+(AY/D)*1.E+15
      RETURN
      END
```

SUBROUTINE INTCPT: LISTING

PURPOSE: To compute the point X4V on a <u>line</u> defined by the points X1V, X2V that is nearest to the point X3V. The length of the <u>line segment</u> (X3V, X4V) is the distance, DIST, from the point X3V to the <u>line</u> defined by X1V, X2V. If DIST =0, then DIST is set equal to 1 foot prior to returning to the calling program.

SUBPROGRAMS USED: DSQR (X1,X2); AMAG (X1, X2)

VARIABLES: <u>Input Parameters</u>

X1V(I), X2V(I) - Points in x, y, z coordinate space defining a line.

X3V(I) - A point in the x, y, z coordinate space.

<u>Subprogram Parameters</u>

I - Subscript denoting coordinate

x - coordinate, I = 1

y - coordinate, I = 2

z - coordinate, I = 3

AV(I) - Components of vector $\vec{R}_{21}$

BV(I) - Components of vector $\vec{R}_{31}$

AX, AY, AZ - Values of AV(1), AV(2), AV(3); respectively.

BX, BY, BZ - Values of BV(1), BV(2), BV(3); respectively.

TEMP - Square of length of line segment defined by X1V, X2V.

SUBROUTINE NRPT (X1V, X2V, X3V, X4V, DIST) Concluded

RATIO - An expression developed in the derivation of the point X4V(I) in terms of X1V(I), X2V(I) and X3V(I).

Output Parameters

X4V(I) - A point on the line defined by X1V(I), X2V(I) that is nearest to the point X3V(I). See RESTRICTIONS.

DIST - The distance from the point X3V(I) to the line defined by X1V(I), X2V(I). If DIST = 0, the subprogram sets DIST = 1 prior to returning control to the calling program. See RESTRICTIONS.

RESTRICTIONS: If the points X1V and X2V coincide, X4V coincides with X1V and DIST is the distance between X3V and X4V. If X3V is on the line defined by X1V, X2V then X4V and X3V coincide and DIST = 1.

REFERENCES: None.

SIZE: 796_8

```
      SUBROUTINE NRPT(X1V,X2V,X3V,X4V,DIST)
C FIND NEAREST POINT TO LINE
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),AV(3),BV(3)
      EQUIVALENCE (AV(1),AX),(AV(2),AY),(AV(3),AZ),(BV(1),BX),(BV(2),BY
     1 ),(BV(3),BZ)
      DO 5 I=1,3
      AV(I)=X2V(I)-X1V(I)
      BV(I)=X3V(I)-X1V(I)
    5 CONTINUE
      RATIO=0.
      TEMP=DSQR(X2V,X1V)
      IF(TEMP.NE.0.)RATIO=(AX*BX+AY*BY+AZ*BZ)/TEMP
      DO 10 I=1,3
      X4V(I)=X1V(I)+RATIO*AV(I)
   10 CONTINUE
      DIST=AMAG(X4V,X3V)
      IF(DIST.EQ.0.)DIST=1.
      RETURN
      END
```

SUBROUTINE NRPT: LISTING

E.13 SUBROUTINE NR1 (X1V, X2V, X3V, X4V, DIST, X5V, DN1)

PURPOSE: To calculate the point, X5V, on the line segment (X1V, X2V) that is nearest to the point X3V and to calculate the distance between the points X3V and X5V.

SUBPROGRAMS USED: KPOS (X1, X2, X3), REPLACE (X1, X2), AMAG (X1, X2)

VARIABLES: <u>Input Parameters</u>

X1V(I), X2V(I) - Points in (x, y, z) coordinate space defining a line segment and a line.

X3V(I) - A point in (x, y, z) coordinate space.

X4V(I) - The point on <u>the line</u> passing through the points X1V, X2V that is nearest to the point X3V.

DIST - The distance from the point X3V to <u>the line</u> passing through the points X1V, X2V.

<u>Output Parameters</u>

X5V(I) - A point on the <u>line segment</u> (X1V, X2V) that is nearest to the point X3V.

DN1 - The length of the line segment (X3V, X5V).

RESTRICTIONS: See Subprogram NRPT.

ACCURACY: Not Applicable.

SIZE: 736_8

REFERENCES: None.

```
      SUBROUTINE NR1(X1V,X2V,X3V,X4V,DIST,X5V,DN1)
C FIND NEAREST POINT TO LINE SEGMENT
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),X5V(3)
      IF(KPOS(X4V,X2V,X1V).EQ.1)GO TO 2
      IF(KPOS(X1V,X4V,X2V).EQ.1)GO TO 4
      CALL REPLCE(X4V,X5V)
      DN1=DIST
      RETURN
    2 CALL REPLCE(X1V,X5V)
      GO TO 6
    4 CALL REPLCE(X2V,X5V)
    6 DN1=AMAG(X5V,X3V)
      RETURN
      END
```

SUBROUTINE NR1: LISTING

E.14 SUBROUTINE ENDPT (X1V, X2V, X3V, X4V, X5V, X6V, KTRIG, IERR) Continued

PURPOSE: To calculate the (x, y, z) coordinates of points on a roadway segment for which sound propagation may or may not be affected at a receiver location by an intervening barrier or ground strip. (See RESTRICTIONS).

The input values of the points X1V, X2V define the initial roadway segment. The point X3V defines the observer location and the points X4V, X5V define the location of a barrier on ground strip.

The subroutine calculates the index KTRIG and,as necessary, the point X6V on the line segment defined by the input values of X1V, X2V so that if KTRIG = 0, the line segment defined by the output values of X1V, X2V represent a road segment with a clear line of sight to the receiver X3V. If KTRIG = 0, the output values of X6V have no physical significance. If KTRIG = 1, the line segment defined by the output values of X1V, X6V represent a road segment with an obstructed (in the x-y plane) line-of-sight to the receiver at X3V and the line segment defined by the output values of X6V, X2V represent a roadway segment with a clear line-of-sight to the receiver at X3V.

The subroutine does not alter the input values of X1V, X3V, X4V, and X5V, but it may alter the input value of X2V. Also, the points X2V and X6V may coincide. (see VARIABLES and RESTRICTIONS).

SUBPROGRAMS USED: REPLCE (X1V, X2V); ZCOR (X1V, X2V, X3V); BLOCN (X1V, X2V, X3V, X4V, X5V, X6V, LOC); MOVE (X1V, X2V, X3V, DELTA, IERR).

SUBROUTINE ENDPT (X1V, X2V, X3V, X4V, X5V, X6V, DTRIG, IERR) Continued

VARIABLES: Input parameters

X1V(I), X2V(I) - Points in x, y, z coordinate space defining the alignment of the roadway segment.

X3V(I) - A point in x, y, z coordinate space defining the receiver location.

X4V(I), X5V(I) - Points in x, y, z coordinate space defining a barrier or a ground strip.

Subprogram parameters

ITRIG - An index, internal to the subprogram, that indicates whether or not the input value of the point X1V and the point X6V initially calculated on the line segment (X1V, X2V) are so close that the significance of the segment (X1V, X6V) can be ignored in judging the effect of the strip (X4V, X5V). The subroutine considers "close" to be a distance of 0.51 feet.

LOC - An index generated by the subroutine BLOCN that indicates the relative location of the roadway segment and the receiver to the barrier or ground strip.

DELTA - A distance defined as either -0.50 or -0.51 feet and used by subroutine MOVE to shift points.

XDUM(I)- A dummy point initially set equal to X4V(I).

Output parameters

KTRIG - An index of whether or not the sound from a road segment may be attenuated by a barrier or ground strip. If KTRIG = 0, the segment (X1V, X2V) is unaffected by the strip X4V, X5V (see Output parameter X2V(I)). If KTRIG = 1, the line segment (X1V, X6V) is totally affected by the strip

(X4V, X5V) and the segment (X6V, X2V) is unaffected by the strip (X4V, X5V) (See Output parameter,X6V(I)).

IERR - An error code set by subroutine MOVE. If IERR = 0, the subroutine MOVE has been successful and output from ENDPT can be used. If IERR = 4, the subroutine MOVE has not been successful and output from ENDPT are probably in error. (See Subroutine MOVE).

X1V(I) - One end point of the roadway segment. The input values of X1V(I) are not altered by the subprogram.

X2V(I) - One end point of the roadway segment. The input values of X2V(I) to ENDPT may be altered by ENDPT so that when KTRIG = 0, the roadway segment defined by (X1V, X2V) is <u>not</u> affected by the barrier or ground strip defined by (X4V, X5V). If KTRIG = 1, the input values of X2V(I) to ENDPT are not altered by the subroutine. Hence, the output values of X2V(I) always represent an end point of a roadway segment that is unaffected by the intervening barrier or ground strip.

X3V(I) - Input values of the receiver location. Not altered by the subprogram.

X4V(I), X5V(I) - Input values of the barrier or ground strip location. Not altered by the subprogram.

X6V(I) - If KTRIG = 0, the point X6V has no significance. If KTRIG = 1, the point X6V is a point on the roadway segment (X1V, X2V) that defines a totally affected segment (X1V, X6V) and a totally unaffected segment (X6V, X2V). The point X6V may coincide with the point X2V.

SUBROUTINE ENDPT (X1V, X2V, X3V, X4V, X5V, X6V, DTRIG, IERR) Concluded

RESTRICTIONS: The subroutine ENDPT determines whether or not the roadway segment defined by the input values of (X1V, X2V) is affected by the barrier or ground strip (X4V, X5V) using x-y coordinate geometry. Hence, the subroutine ENDPT does make an absolute judgement as to no effect if KTRI = 0 on the segment (X1V, X2V) or if KTRI = 1 on the segment (X6V, X2V). However, if KTRI = 1, the subroutine does not consider the elevations of source, barrier, and receiver for the roadway segment (X1V, X6V). The usage should recognize this fact.

ACCURACY: That of subprograms.

SIZE: 1152_8

REFERENCES: None.

```
      SUBROUTINE ENDPT(X1V,X2V,X3V,X4V,X5V,X6V,KTRIG,IERR)
C FIND NEW ENDPOINT
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/INOU/INPT,IOUT
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),X5V(3),X6V(3),XDUM(3)
      IERR=0
      KTRIG=0
      ITRIG=1
      CALL REPLCE(X1V,XDUM)
    1 CALL BLOCN(XDUM,X2V,X3V,X4V,X5V,X6V,LOC)
      IF(LOC.EQ.0) RETURN
      IF(LOC.NE.3) GO TO 2
      CALL REPLCE(X2V,X6V)
      GO TO 4
    2 X6V(3)=ZCOR(X1V,X2V,X6V)
      IF(ITRIG.EQ.0) GO TO 5
      IF(AMAG(X1V,X6V).GT.0.51) GO TO 5
      ITRIG=0
      DELTA=-0.51
      CALL MOVE(XDUM,XDUM,X2V,DELTA,IERR)
      GO TO 1
    5 DELTA=-0.5
      IF(LOC.EQ.1) GO TO 3
      CALL MOVE(X6V,X2V,X1V,DELTA,IERR)
      RETURN
    3 CALL MOVE(X6V,X6V,X1V,DELTA,IERR)
    4 KTRIG=1
      IF (IERR.EQ.4) WRITE(IOUT,1000)
 1000 FORMAT(14H ERROR IN MOVE)
      RETURN
      END
```

SUBROUTINE ENDPT: LISTING

E.15 SUBROUTINE SECTN (X1V, X2V, X3V, X4V, X5V, X6V, X7V) Continued

PURPOSE: Calculates the (x, y, z) coordinates of the points X6V(I) and X7V(I). The point X6V(I) is on the line passing through the points X4V, X5V intersecting the vertical (z - coordinate) plane defined by the (x-y) coordinates of the points X1V, X3V. The point X7V is on the line passing through the points X4V, X5V intersecting the vertical (z - coordinate) plane defined by the (x-y) coordinates of the points X2V, X3V. (See RESTRICTIONS and Figure E-3).

SUBPROGRAMS USED: INTCPT (X1, X2, X3, X4, X5), ZCOR (X1, X2, X3)

VARIABLES: Input Parameters

X1V(I), X2V(I), X3V(I) - Points in (x, y, z) coordinate space defining lines passing through the points X1V, X3V and X2V, X3V.

X4V(I), X5V(I) - Points in the (x, y, z) coordinate space defining a line passing through the points X4V, X5V.

Output Parameters

X6V(I), X7V(I) - Points on the line passing through the points X4V, X5V that lie in the vertical plane defined by the x-y components of the lines passing through the points X1V, X3V and X2V, X3V, respectively.

RESTRICTIONS: The subprogram does not check to see if the points X6V and X7V lie on the line segment (X4V, X5V). Usage of this subprogram must recognize this restriction.

ACCURACY: See Subprogram INTCPT.

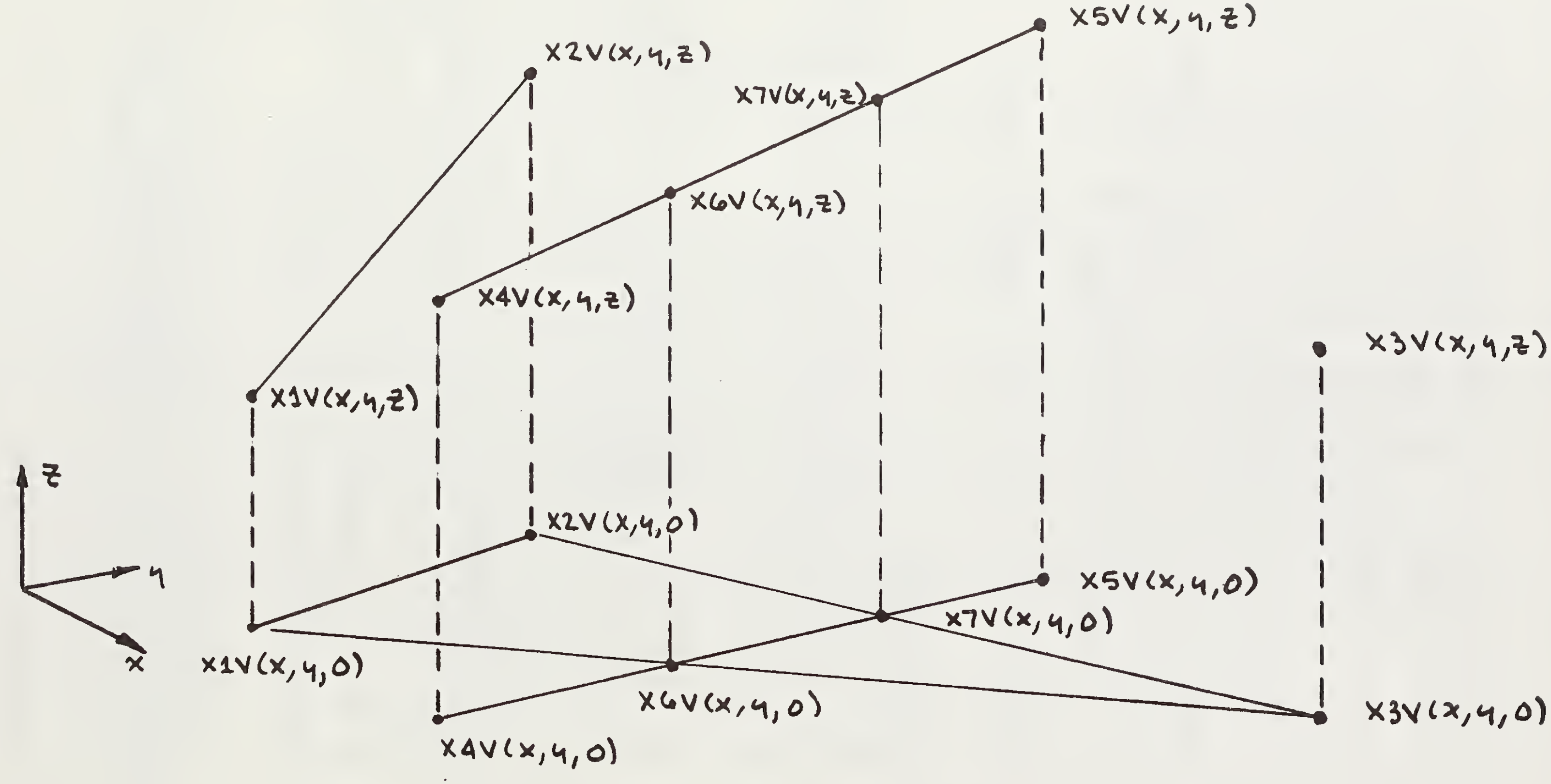


FIGURE E-3. SUBROUTINE SECTN: NOMENCLATURE

SUBROUTINE SECTN (X1V, X2V, X3V, X4V, X5V, X6V, X7V) Concluded

SIZE: 634_8

REFERENCES: None.

```
      SUBROUTINE SECTN(X1V,X2V,X3V,X4V,X5V,X6V,X7V)
C  FIND EFFECTIVE BARRIER SECTION
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),X5V(3),X6V(3),X7V(3)
      CALL INTCPT(X1V,X3V,X4V,X5V,X6V)
      X6V(3)=ZCOR(X4V,X5V,X6V)
      CALL INTCPT(X2V,X3V,X4V,X5V,X7V)
      X7V(3)=ZCOR(X4V,X5V,X7V)
      RETURN
      END
```

SUBROUTINE SECTN: LISTING

E.16 SUBROUTINE IMAGE(X1V, X2V, X3V, X4V) Continued

PURPOSE: To calculate the (x, y, z) (I = 1,2,3) location of an image receiver at the point X4V(I) relative to a receiver at the point X3V(I) and a reflector defined by the end points X1V(I) and X2V(I). All calculations are conducted in the x-y plane with the z coordinate, X4V(3), of the image receiver set equal to the z coordinate X3V(3) of the receiver.

SUBPROGRAMS USED: None.

VARIABLES: <u>Input parameter</u>

X1V(I), X2V(I) - The x, y, z coordinates of the reflector.

X3V(I) - The x, y, z coordinates of the receiver.

<u>Subprogram parameters</u>

AX - The x-component of the <u>directed</u> line segment (X1V, X2V)

AY - The y-component of the <u>directed</u> line segment (X1V, X2V).

AXY - The square of the distance of the x-y plane projection of the line segment (X1V, X2V).

RATIO - The ratio of the x-y plane projections of the distance of point X3V from the line defined by X1V, X2V to the length of the line segment (X1V, X2V).

<u>Output parameters</u>

X4V(I) - The (x, y, z) coordinates of the image receiver.

RESTRICTIONS: The subroutine does not utilize the z coordinates defining the reflector and, hence, cannot judge whether or not a reflection would in fact occur. Usage should recognize this restriction.

ACCURACY: Not applicable.

SUBROUTINE IMAGE(X1V, X2V, X3V, X4V) Concluded

SIZE: 532_8

REFERENCES: See Figure E-4 for nomenclative.

```
      SUBROUTINE IMAGE(X1V,X2V,X3V,X4V)
C FIND IMAGE POINT
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3)
      AX=X2V(1)-X1V(1)
      AY=X2V(2)-X1V(2)
      AXY=AX**2+AY**2
      RATIO=0.
      IF(AXY.EQ.0.)GO TO 10
      RATIO=(((X3V(2)-X2V(2))*AX-(X3V(1)-X2V(1))*AY)*2.0)/AXY
   10 X4V(1)=X3V(1)+AY*RATIO
      X4V(2)=X3V(2)-AX*RATIO
      X4V(3)=X3V(3)
      RETURN
      END
```

SUBROUTINE IMAGE: LISTING

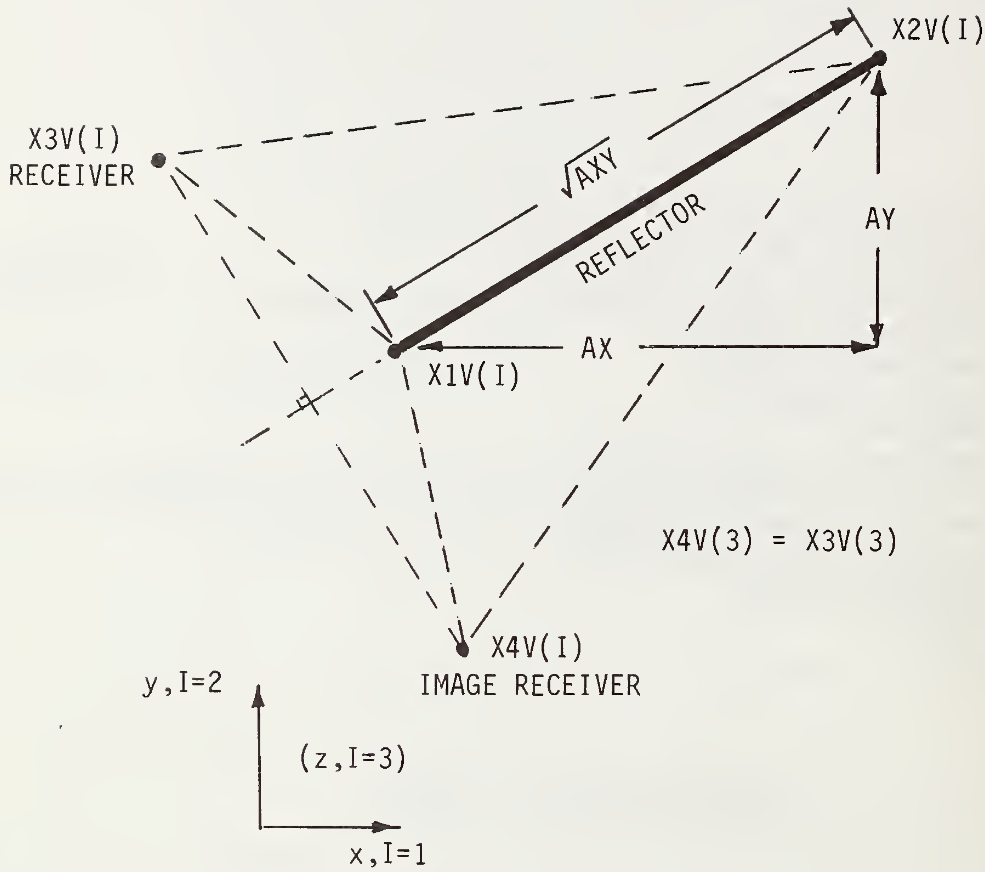


FIGURE E-4. SUBROUTINE IMAGE: NOMENCLATURE

E.17 SUBROUTINE MIDP (X1V, X2V, X3V)

PURPOSE: To calculate the midpoint, X3V, of a line segment defined by the points (X1V, X2V) in x, y, z coordinate space.

SUBPROGRAMS USED: None.

VARIABLES: <u>Input parameters</u>

X1V(I), X2V(I) - Points in x, y, z coordinate space defining the line segment.

I - Subscript defining the
  x - component I = 1
  y - component I = 2
  z - component I = 3
of the points X1V(I), X2V(I), X3V(I).

<u>Output parameter</u>

X3V(I) - Point in x, y, z coordinate spece defining the midpoint of the line segment (X1V, X2V).

RESTRICTIONS: None

ACCURACY: Not applicable

SIZE: 402_8

REFERENCES: None

```
      SUBROUTINE MIDP (X1V, X2V, X3V)
C     FIND CENTER POINT
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(3), X2V(3), X3V(3)
      DO 10 I=1,3
   10 X3V(I) = (X1V(I)+X2V(I))/2.
      RETURN
      END
```

SUBROUTINE MIDP: LISTING

E.18 SUBROUTINE REPLCE (X1V, X2V)

PURPOSE: To assign the coordinates of a point or the components of a vector, X1V(I), to the coordinates of a point or the components of a vector X2V(I). The values of X1V(I) are unchanged.

SUBPROGRAMS USED: None.

VARIABLES: <u>Input/Output Parameters</u>

X1V(I), X2V(I) - The components of two vectors or the coordinates of two points in (x, y, z) coordinate space.

x - component or coordinate I = 1

y - component or coordinate I = 2

z - component or coordinate I = 3

RESTRICTIONS: None.

ACCURACY: Not applicable.

SIZE: 310_8

REFERENCES: None.

```
      SUBROUTINE REPLCE(X1V,X2V)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(3),X2V(3)
      X2V(1)=X1V(1)
      X2V(2)=X1V(2)
      X2V(3)=X1V(3)
      RETURN
      END
```

SUBROUTINE REPLCE: LISTING

E.19 FUNCTION AMAG (X1V, X2V)

PURPOSE: To compute the length, AMAG, of a line segment defined by the end points X1V(I) and X2V(I), for an (x, y, z) coordinate system.

SUBPROGRAMS LISTED: DSQR (X1V, X2V); SQRT (X).

VARIABLES: Input Parameters

X1V(I), X2V(I) - Points defined by their x(I=1), y(I=2), z(I=3) coordinates.

RESTRICTIONS: None.

ACCURACY: Not Applicable.

SIZE: 370_8

REFERENCES: Calculates the length of a line vector, $\vec{R}_{12}$, as AMAG = $(\vec{R}_{12} \cdot \vec{R}_{12})^{\frac{1}{2}}$.

```
0001          FUNCTION AMAG(X1V,X2V)
        C FIND MAGNITUDE OF VECTOR
0002          IMPLICIT REAL*8 (A-H,O-Z)
0003          DIMENSION X1V(3),X2V(3)
0004          AMAG=DSQRT(DSQR(X1V,X2V))
0005          RETURN
0006          END
```

FUNCTION AMAG: LISTING

E.20 FUNCTION ANGLE (X1V, X2V, X3V)

PURPOSE: To compute the angle between the two line segments defined by the points (X1V, X3V) and (X2V, X3V) for an (x, y, z) coordinate system.

SUBPROGRAMS LISTED: DSQR (X1, X2), SQRT (X), ARCOS (X).

VARIABLES: <u>Input Parameters</u>

X1V(I), X2V(I), X3V(I) - Points defined by their x(I=1), y(I=2), z(I=3) coordinates.

<u>Subprogram Parameters</u>

D13 - Square of the length of the line segment defined by the points X1V(I) and X3V(I).

D12 - Square of the length of the line segment defined by the points X1V(I) and X2V(I).

D23 - Square of the length of the line segment defined by the points X2V(I) and X3V(I).

RESTRICTIONS: If point X3V coincides with either X1V or X2V, ANGLE = $\pi/2$.

ACCURACY: That of subprograms.

SIZE: 624_8

REFERENCES: COS (ANGLE) is calculated using the "Law of Cosines." ANGLE is calculated as $\cos^{-1}$ (COS(ANGLE)).

FUNCTION ANGLE: LISTING

```
      FUNCTION ANGLE(X1V,X2V,X3V)
       IMPLICIT REAL*8 (A-H,O-Z)
       DIMENSION X1V(3),X2V(3),X3V(3)
       D13=DSQR(X1V,X3V)
      D23=DSQR(X2V,X3V)
       ANGLE=1.5708
       IF(D13*D23 .EQ. 0.)RETURN
      D12=DSQR(X1V,X2V)
      ANGLE=DARCOS((D23+D13-D12)/(DSQRT(D13*D23)*2.))
      RETURN
       END
```

E.21 FUNCTION BARFAC (KF, DELP) Continued

PURPOSE: To compute the attenuation of acoustic intensity for a propagation path over a barrier between a source point and a receiver point for a given path length difference, DELP, and octave band center frequency, denoted by the index KF.

SUBPROGRAMS LISTES: SQRT(X), TAN(X), TANH(X), ABS(X).

VARIABLES: Input parameters

KF - Interger index, n, for octave band center frequency (see derivation below) or A-weighted sound level, (KF = 1).

Subprogram parameters

DELP - Path length difference, δ, between the diffracted ray and the direct ray between source and receiver.

IP - Variable internal to subprogram equal to KF.

A - $2\pi N$, where N is the Fresnel Number (see derivation below).

RESTRICTION: Theory based upon Fresnel diffraction using an analytical approximation to the experimental measurements of Maekawa. (See Section A.6, Appendix A).

If KF=1, the A-weighted sound level is being utilized. This subprogram evaluates A-weighted sound level attenuation by calculating the attenuation at the octave-band center frequency of 500 Hz. (IP=5).

Speed of sound, c, is assumed to be 1120 ft/sec.

ACCURACY: That of subprograms.

SIZE: 856_8

FUNCTION BARFAC (KF, DELP) Continued.

REFERENCES: Maekawa, Z.: "Noise Reduction by Screens; Applied Acoustics, Vol. 1, 1968, pp 157-173.

Kurze, U.J., and Anderson, G.S.; "Sound Attenuation by Barriers", Applied Acoustics, Vol. 4, 1971, pp 35-53.

Kurze, U.J.; "Noise Reduction by Barriers", J. Acoustical Society of America, Vol. 55, No. 3, March 1974, pp 504-518.

DERIVATION: Development of the relationship for calculating the barrier factor (attenuation) as a function of Fresnel Number is presented in Section

For an octave band center frequency, f_c; a path length difference, δ; and a speed of sound, c; the Fresnel Number is defined as

$$N = 2f_c \delta / c$$

for $f_c = 2^n \cdot 10^3/64$; $n = 2,3,....9$, $c = 1120$ ft/sec.

$$N = 2f_c \delta/1120 = f_c \delta/560$$

$$N = 2^n \cdot 10^3 \delta/(64 \cdot 560) = 2^n \delta/(35.34)$$

$$A = 2\pi N = 2^n \delta/(35.84/2\pi) = 2^n \delta/5.7$$

$$BARFAC = 10^{-D_b/10}$$

for $N \leq -0.2$; $A \leq -1.257$; $D_b=0$; BARFAC=1.0

for $-0.2 \leq N \leq 0$ $-1.257 \leq A \leq 0$

$$D_b = 20 \cdot \log\ (\sqrt{|A|}/TAN(\sqrt{|A|})) + 5 = 20 \log (R) + 5$$

$$BARFAC = 10^{-(20 \log (R) + 5)/10} = (10^{0.5} R^2)^{-1}$$

$$BARFAC = (3.1623\ R^2)^{-1} = (TAN(\sqrt{|A|})/\sqrt{|A|})^2/3.16$$

for $N=0$; $A=0$; $D_b=5$; $BARFAC = 10^{-5/10} = 0.31623$

for $0 \leq N \leq 5.03$; $0 \leq A \leq 31.6$;

$$D_b = 20 \cdot \log\ (\sqrt{A}/TAN\ H(\sqrt{A})) + 5 = 20 \log (R) + 5$$

FUNCTION BARFAC (KF, DELP) Concluded

$$BARFAC = 10^{-(20 \cdot \log (R) + 5)/10}$$

$$= (3.1623\ R^2)^{-1} = (TANH(\sqrt{A}))^2/3.16A$$

for $N > 5.03$; $A \geq 31.6$ $D_b = 20^*$

$$BARFAC = 10^{-20/10} = 10^{-2} = 0.0100$$

* Note: Previous versions of this subroutine placed an upper limit of D_b = 24 dB on barrier attenuation (ie, $BARFAC = 4 \cdot 10^{-3}$). The upper limit has been reduced to 20 dB based upon field experience.

```
      FUNCTION BARFAC(KF,DELP)
      IMPLICIT REAL*8 (A-H,O-Z)
C FIND BARRIER FACTOR
      IF(DELP.EQ.-0.2)GO TO 3
      IF(DELP.GE.5.65)GO TO 4
      IP=KF
      IF(KF.EQ.1)IP=5
      A=DELP*(2.**IP)/5.7
      IF(A.GE.31.6)GO TO 4
      IF(A.GT.0.) GO TO 5
      IF(A.EQ.0.)GO TO 6
      IF(A.GT.-1.25.AND.A.LT.0.)GO TO 7
    3 BARFAC=1.0
      RETURN
    4 BARFAC=0.01
      RETURN
    5 BARFAC=(DTANH(DSQRT(A))**2)/A/3.16
      RETURN
    6 BARFAC=.316
      RETURN
    7 A1=DABS(A)
      BARFAC=(DTAN(DSQRT(A1)))**2/A1/3.16
      RETURN
      END
```

FUNCTION BARFAC: LISTING

E.22 FUNCTION DEL (X1V, X2V, X3V, X4V, HDIFF, DN1) Continued

PURPOSE: To calculate the path length difference, DEL, between the ray from the source point, X1V(I), diffracted over a barrier defined by a line segment defined by the points (X3V(I), X4V(I)) towards a receiver location at the point X2V(I). Points and line segments are defined in an x(I = 1), y(I =2), z(I = 3) coordinate system.

SUBPROGRAMS USED: NRPT (X1, X2, X3, X4, DIST), DSQR (X1, X3), SQRT (X).

VARIABLES: Input parameters

X1V(I) - Source point at x(I = 1), y(I = 2), z(I = 3)

X2V(I) - Receiver point at x(I = 1), y(I = 2), z(I = 3)

X3V(I) - End point of line segment at x(I = 1), y(I = 2), z(I = 3) defining barrier.

X4V(I) - End point of line segment at x(I = 1), y(I = 2), z(I = 3) defining barrier.

HDIFF - Height difference between source-receiver ray and top of barrier. (See function HEIGHT).

DN1 - Distance between source-receiver.

Subprogram parameters

DISTA - Distance from source to point XA(I).

DISTB - Distance from receiver to point XB(I).

DISTC - Square of distance between points XA(I) and XB(I).

XA(I) - Point on line defined by the line segment (X3V, X4V) that is nearest to the source point X1V(I).

XB(I) - Point on line defined by the line segment (X3V, X4V) that is nearest to the receiver point X2V(I).

Output parameters

DEL - Path length difference. Positive if HDIFF is less than zero. Negative if HDIFF is greater than zero.

FUNCTION DEL (X1V, X2V, X3V, X4V, HDIFF, DN1) Concluded

RESTRICTIONS: The subprogram does not check to see if the direct path from the source to the receiver intersects the barrier. Hence, it is possible to define input to the subroutine that yields a positive value of DEL when in fact DEL should be zero. Usage of this subroutine should recognize this restriction.

ACCURACY: That of subprograms.

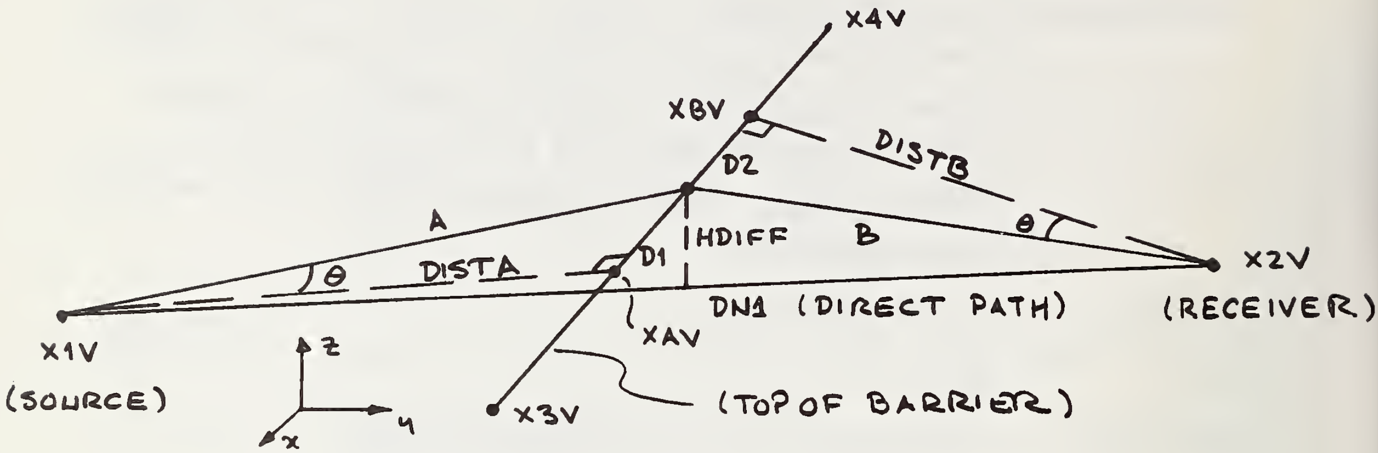
SIZE: 672_8

REFERENCES: See Figure E-5 for derivation of algorithm.

```
      FUNCTION DEL(X1V,X2V,X3V,X4V,HDIFF,DN1)
C  FIND PATH LENGTH DIFFERENCE
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),XAV(3),XBV(3)
      CALL NRPT(X3V,X4V,X1V,XAV,DISTA)
      CALL NRPT(X3V,X4V,X2V,XBV,DISTB)
      DISTC=DSQR(X3V,XAV)
      DEL=DSQRT((DISTA+DISTB)**2+DISTC)-DN1
      IF(HDIFF.GT.O.)DEL=-DEL
      RETURN
      END
```

FUNCTION DEL: LISTING

FUNCTION DEL (X1V,X2V,X3V,X4V,HDIFF,DN1)



Basic Relationship: DEL = A + B - DN1

Basic Geometry:

$$DISTA = A \cos \theta \qquad D1 = A \, SIN \, \theta$$
$$DISTB = B \cos \theta \qquad D2 = B \, SIN \, \theta$$
$$A^2 = DISTA^2 + D1^2 \qquad B^2 = DISTB^2 + D2^2$$

$$DISTA \bullet DISTB + D1 \bullet D2 = AB \cos^2\theta + AB \, SIN^2\theta = AB$$

$$(A + B)^2 = A^2 + B^2 + 2AB$$
$$(A + B)^2 = DISTA^2 + D1^2 + DISTB^2 + D2^2 + 2\,(DISTA \bullet DISTB + D1 \bullet D2)$$
$$(A + B)^2 = (DISTA + DISTB)^2 + (D1 + D2)^2$$
$$DISTC = (D1 + D2)^2$$

$$\therefore A + B - DN1 = SQRT((DISTA + DISTB)^2 + DISTC) - DN1$$

FIGURE E-5. FUNCTION DEL: DERIVATION

E.23 FUNCTION DSQR (X1V, X2V)

PURPOSE: To calculate the square of the distance between two points X1V(I), X2V(I) in x(I = 1), y(I = 2), z(I = 3) space.

SUBPROGRAMS USED: None.

VARIABLES: <u>Input parameters</u>

X1V(I), X2V(I) - Points defining a line segment by their x, y, z coordinates.

<u>Output parameters</u>

DSQR - The square of the distance between the points X1V(I), X2V(I).

RESTRICTIONS: None.

ACCURACY: Not applicable.

SIZE: 392_8

REFERENCES: DSQR is the scalar ("dot") product of the vector between points X1V and X2V.

$$DSQR = \vec{R}_{12} \cdot \vec{R}_{12} = \vec{R}_{21} \cdot \vec{R}_{21}$$

FUNCTION DSQR: LISTING

```
      FUNCTION DSQR(X1V,X2V)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION  X1V(3),X2V(3)
      DSQR=0.0
      DO 10 I=1,3
   10 DSQR=(X1V(I)-X2V(I))**2+DSQR
      RETURN
      END
```

E.24 FUNCTION HEIGHT (X1V, X2V, X3V, X4V)

PURPOSE: To calculate the difference in elevation (z coordinates) between the lines defined by the points (X1V, X2V) and (X3V, X4V) at the x-y plane intersection point of the x-y plane projections of the lines (X1V, X2V) and (X3V, X4V).

SUBPROGRAMS USED: INTCPT (X1, X2, X3, X4, X5) ZCOR (X1, X2, X3).

VARIABLES: Input parameters

X1V(I), X2V(I) - Two points defining a line in x(I = 1), y(I = 2), z(I = 3) coordinates.

X3V(I), X4V(I) - Two points defining a line in x(I = 1), y(I = 2), z(I = 3) coordinates.

Subprogram parameters

XI(I) - The x-y plane intersection point of the x-y plane projections of lines defined by the points (X1V, X2V) and (X3V, X4V). Note XI(3) is never assigned a value.

Output parameters

HEIGHT - Difference in elevation between lines defined by (X1V, X2V) and (X3V, X4V) at intersection point.

RESTRICTIONS: That of subprograms used. Hence, HEIGHT can be an elevation difference at a location not on the line segment defined by (X1V, X2V) and (X3V, X4V). See Subprograms INTCPT and ZCOR.

ACCURACY: If the x-y plane projections of the lines (X1V, X2V) and (X3V, X4V) are parallel on collinear HEIGHT will be a very large number. See Subprograms INTCPT and ZCOR.

SIZE: 518_8

REFERENCES: See Subprograms INTCPT and ZCOR.

```
      FUNCTION HEIGHT(X1V,X2V,X3V,X4V)
C FIND HEIGHT DIFFERENCE
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),XI(3)
      CALL INTCPT(X1V,X2V,X3V,X4V,XI)
      HEIGHT=ZCOR(X1V,X2V,XI)-ZCOR(X3V,X4V,XI)
      RETURN
      END
```

FUNCTION HEIGHT: LISTING

PURPOSE: To calculate an index, IAREA, that indicates the relative spacing (area enclosed) of the three points X1V, X2V, X3V in the x-y plane.

SUBPROGRAMS USED: ABS(X)

VARIABLES: Input Parameters

X1V(I), X2V(I), X3V(I) - Points defined in the x-y plane.

x - coordinate I = 1

y - coordinate I = 2

Subprogram Parameters

TERM 1, TERM 2, TERM 3 - The three terms resulting from calculating the vector ("cross") product of the vectors $\vec{R}_{31}$ and $\vec{R}_{32}$.

AREA - A number equal to twice the area of the triangle formed by the points X1V, X2V, X3V. Area may be positive or negative depending upon the locations of points X1V, X2V relative to X3V. If AREA is zero, the points X1V, X2V, X3V are colinear. (See REFERENCES).

Output Parameters

IAREA: IAREA = 1 if the area of the triangle formed by X1V, X2V, X3V is greater than 1 square foot.

IAREA =-0 if the area of the triangle formed by X1V, X2V, X3V is equal to or greater than zero square feet but less than or equal to 1 square foot.

IAREA = 1 if the variable AREA is negative (See REFERENCES).

FUNCTION IAREA (X1V, X2V, X3V) Concluded

RESTRICTIONS: None.

ACCURACY: Not applicable.

SIZE: 516_8

REFERENCES: The variable AREA is the magnitude of the vector formed by the vector product of the vectors $\vec{R}_{31}$ and $\vec{R}_{32}$ in the x-y plane.

```
      FUNCTION IAREA(X1V,X2V,X3V)
C FIND AREA OF TRIANGLE
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(2),X2V(2),X3V(2)
      IAREA=1
      TERM1=X1V(1)*(X2V(2)-X3V(2))
      TERM2=X2V(1)*(X3V(2)-X1V(2))
      TERM3=X3V(1)*(X1V(2)-X2V(2))
      AREA=TERM1+TERM2+TERM3
      IF(AREA.LT.0.0) IAREA=-1
      IF (DABS(.5*AREA).LE.1.) IAREA=0
      RETURN
      END
```

FUNCTION IAREA: LISTING

PURPOSE: The decision parameter IEPS represents a comparison of two path length differences, DEL1 and DEL2, to decide whether or not the path length differences are sufficiently similar so that the condition of uniform sound intensity from a roadway segment to a receiver via a diffracted path over a barrier exists. If IEPS = 0, the condition of uniform sound intensity at the receiver is satisfied and DEL2 is considered similar to DEL1. If IEPS = 1, DEL2 is not sufficiently similar to DEL1 for uniform sound intensity at the receiver to be assumed.

SUBPROGRAMS USED: AMAG(X1, X2); HEIGHT(X1, X2, X3, X4); (DEL(X1, X2, X3, X4), (HDIFF, DIST); ABS(X).

VARIABLES: Input parameters

X1V(I) - A point in (x, y, z) coordinate space that represents the source.

X2V(I) - A point in (x, y, z) coordinate space that represents the receiver.

X3V(I), X4V(I) - Two points in (x, y, z) coordinate space that define a line representing the top of a barrier.

DEL1 - A number representing a path length difference for an acoustic propagation path diffracting over a barrier.

Subprogram parameters

DIST - The distance between the source point X1V(I) and the receiver point X2V(I).

HDIFF - The elevation difference (difference in z coordinates) between points on the lines defined by the points X1V, X2V and X3V, X4V at the x-y plane intersection point of these lines (See RESTRICTIONS).

FUNCTION IEPS (X1V, X2V, X3V, X4V, DEL1) Concluded

DEL2 - The path length difference defined by the source location, X1V; the receiver location, X2V; and the top of a barrier defined by the line through the points X3V, X4V. (See RESTRICTIONS and Subprogram DEL).

DELM - The arithemetic average of the values of DEL1 and DEL2.

Output parameter

IEPS - IEPS = 0 if the values of DEL1 and DEL2 satisfy the cirterion presented under REFERENCES. (See PURPOSE) IEPS = 1 if the values of DEL1 and DEL2 do not satisfy the criterion presented under REFERENCES. (See PURPOSE).

RESTRICTION: Neither the subprogram IEPS nor any of the subprograms utilized by IEPS checks to see if the line segment (X1V, X2V) intersects the line segment (X3V, X4V). For proper utilization this subprogram must receive input data such that the above line segments do intersect and that the variable DEL1 corresponds to a path length difference associated with the input data geometry. Usage should recognize this restriction. (See Subprogram DEL).

ACCURACY: That of subprograms used and the criterion specified. (See REFERENCES).

SIZE: 700_8

REFERENCES: The criterion used to judge similarity of two path length differences is that

$$|\delta_2 - \delta_1| - \frac{(\delta_2 + \delta_1)}{100} (1 + (\delta_2 + \delta_1)/2) \leq 0.10$$

Where δ_1 = DEL1, δ_2 = DEL2. See description of barrier diffraction under Prediction Model in main text of report.

```
      FUNCTION IEPS (X1V, X2V, X3V, X4V, DEL1)
C     CHECK ON PATH LENGTH DIFFERENCE
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3)
      IEPS =0
      DIST = AMAG (X1V,X2V)
      HDIFF = HEIGHT (X1V,X2V,X3V,X4V)
      DEL2 = DEL (X1V, X2V, X3V, X4V, HDIFF, DIST)
      DELM= (DEL1+DEL2)/2.
      IF ((DABS(DEL2-DEL1)-0.1-DELM/50.*(1.+DELM)) .GT.0.) IEPS=1
      RETURN
      END
```

FUNCTION IEPS: LISTING

E.27 FUNCTION KCUT (X1V, X2V, X3V, X4V)

PURPOSE: To calcualte a logic number, KCUT, that indicates whether or not two line segments intersect in the x-y plane. The line segments are defined by the end points (X1V, X2V) and (X3V, X4V). If the line segments intersect (including end points) KCUT = 1. Otherwise, KCUT = 0.

SUBPROGRAMS USED: INTCPT (X1, X2, X3, X4, X5), KPOS (X1, X2, X3).

VARIABLES: <u>Input parameters</u>

X1V(I), X2V(I) - Points in the x-y plane defining a line segment. The subscript I = 1 for x-coordinates; I = 2 for y-coordinates.

X3V(I), X4V(I) - Points in the x-y plane defining a line segment. The subscript I = 1 for x-coordinates; I = 2 for y-coordinates.

<u>Output parameters</u>

KCUT = 1 - if the line segments intersect in an oblique sense including end points.

KCUT = 0 - if the line segments do not intersect or are collinear.

RESTRICTIONS: If the line segments are collinear, KCUT = 0. See Subprogram INTCPT. Usage should recognize this restriction.

ACCURACY: Not applicable.

SIZE: 544_8

REFERENCES: None.

FUNCTION KCUT: LISTING

```
      FUNCTION KCUT(X1V,X2V,X3V,X4V)
C DETERMINE IF TWO LINE SEGMENTS CROSS
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(2),X2V(2),X3V(2),X4V(2),X5V(2)
      KCUT=0
      CALL INTCPT(X1V,X2V,X3V,X4V,X5V)
      IF(KPOS(X1V,X2V,X5V).NE.1)RETURN
      IF(KPOS(X3V,X4V,X5V).EQ.1)KCUT=1
      RETURN
      END
```

E.28 FUNCTION KPOS (X1V, X2V, X3V)

PURPOSE: To calculate a logic number, KPOS, indicating whether the point X3V, in the x-y plane lies on a line segment defined by the points X1V, X2V in the x-y plane. If X3V lies on the line segment (including the end points) KPOS = 1. If X3V does not lie on the line segment KPOS = 0. (See RESTRICTIONS).

SUBPROGRAMS USED: None.

VARIABLES: Input parameters

X3V(I) - A point in the x-y plane defined by the x-coordinate (I = 1) and the y-coordinate (I = 2).

X1V(I), X2V(I) - Points in the x-y plane defined by the x-coordinate (I = 1) and the y-coordinate (I = 2).

Output parameters (SEE RESTRICTIONS)

KPOS = 1 - If X3V lies on the line segment X1V, X2V.

KPOS = 0 - If X3V does not lie on the line segment X1V, X2V.

RESTRICTIONS: The criteria used to judge if X3V is on the line is $\vec{R}_{12} \cdot \vec{R}_{23} > 0$. Hence, it is possible for X3V to lie off the line segment and still obtain KPOS = 1. Usage should recognize this fact.

ACCURACY: See RESTRICTIONS.

SIZE: 390_8

REFERENCES: None.

```
0001        FUNCTION KPOS(X1V,X2V,X3V)
     C FIND POSITION OF POINT ON LINE
0002        IMPLICIT REAL*8 (A-H,O-Z)
0003        DIMENSION X1V(2),X2V(2),X3V(2)
0004        KPOS=1
0005        IF(((X3V(1)-X1V(1))*(X3V(1)-X2V(1))+(X3V(2)-X1V(2))*(X3V(2)-X2V(2)
           1)).GT.0.)KPOS=0
0006        RETURN
0007        END
```

FUNCTION KPOS: LISTING

E.29 FUNCTION ZCOR (X1V, X2V, X3V)

PURPOSE: To calculate the z - coordinate, X3V(3), of a point X3V(I) on a line defined by the points X1V(I) and X2V(I).

SUBPROGRAMS USED: ABS(X)

VARIABLES: Input Parameters

X1V(I), X2V(I) - Points in (x, y, z) coordinate space defining a line.

X3V(1), X3V(2) - The x-coordinate and the y-coordinate of the point X3V. (See RESTRICTIONS).

Output Parameter

X3V(3) - The z-coordinate of the point X3V. (See RESTRICTIONS).

RESTRICTIONS: The subroutine does not check to see if the x-y coordinates of X3V fall on the x-y plane projection of the line through the points X1V, X2V. Usage of the subroutine should reflect this restriction.

The points X1V, X2V must neither coincide nor define a line parallel to the z-axis.

ACCURACY: Not applicable.

SIZE: 490_8

REFERENCES: None.

```
      FUNCTION ZCOR(X1V,X2V,X3V)
C FIND Z COORDINATE
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X1V(3),X2V(3),X3V(3)
      TEM1=X2V(1)-X1V(1)
      TEM2=X2V(2)-X1V(2)
      TEM3=X2V(3)-X1V(3)
      IF (DABS(TEM1) GT DABS(TEM2)) GO TO 10
      ZCOR=X1V(3)+(X3V(2)-X1V(2))*TEM3/TEM2
      RETURN
    1 ZCOR=X1V(3)+(X3V(1)-X1V(1))*TEM3/TEM1
      RETURN
      END
```

FUNCTION ZCOR: LISTING

E.30 SUBROUTINE GEOMRY(XR, YR, ZR, XR10, XR20, IERR, MR)

PURPOSE

This subroutine conducts the bulk of the calculation effort of the highway traffic noise prediction code. Basically, subroutine GEOMRY considers a receiver location defined by the coordinates XR, YR, ZR and a straight line roadway segment defined for roadway number MR with end points XR10 and XR20. This defines the basic roadway/receiver geometry and traffic flow conditions as indicated in Figure A-1, Appendix A. The error code, IERR, is generated in subroutines MOVE and MOVE2 (IERR=4) or if too many reflections have occurred (IDXR greater than 11, IERR = 3).

Using the basic assumption of uniform reception of acoustic intensity at the receiver location, subroutine GEOMRY considers attenuation by barrier diffraction or ground absorption or amplification by reflection from barriers. It is an understatement to say that the subroutine is complex. Subroutine GEOMRY considers all site-related geometric and acoustic parameters to estimate the normalized acoustic intensity (Equation A-11) and the normalized value of the cumulant, κ_2 (Equation A-35) at a receiver for a straight line roadway segment. Subroutine GEOMRY is called by the MAIN PROGRAM for all segments defining a roadway and for all roadways for each receiver location (See Figure D-2). The summation of acoustic intensity and calculation of the cumulant at each receiver is accomplished by the call statement to GEOMRY from the MAIN PROGRAM and branching internal to GEOMRY. Consideration of vehicle types and spectra calculations defined by the user are conducted internally in subroutine GEOMRY. The vast bulk of data utilized by GEOMRY is transferred through the various COMMON data blocks (See Appendix C).

The basic organization of subroutine GEOMRY is illustrated in Figure E-6. For the basic roadway/receiver geometry (a plane triangle defined by the end points of the roadway segment and the receiver),

AN OVERVIEW OF SUBROUTINE GEOMRY

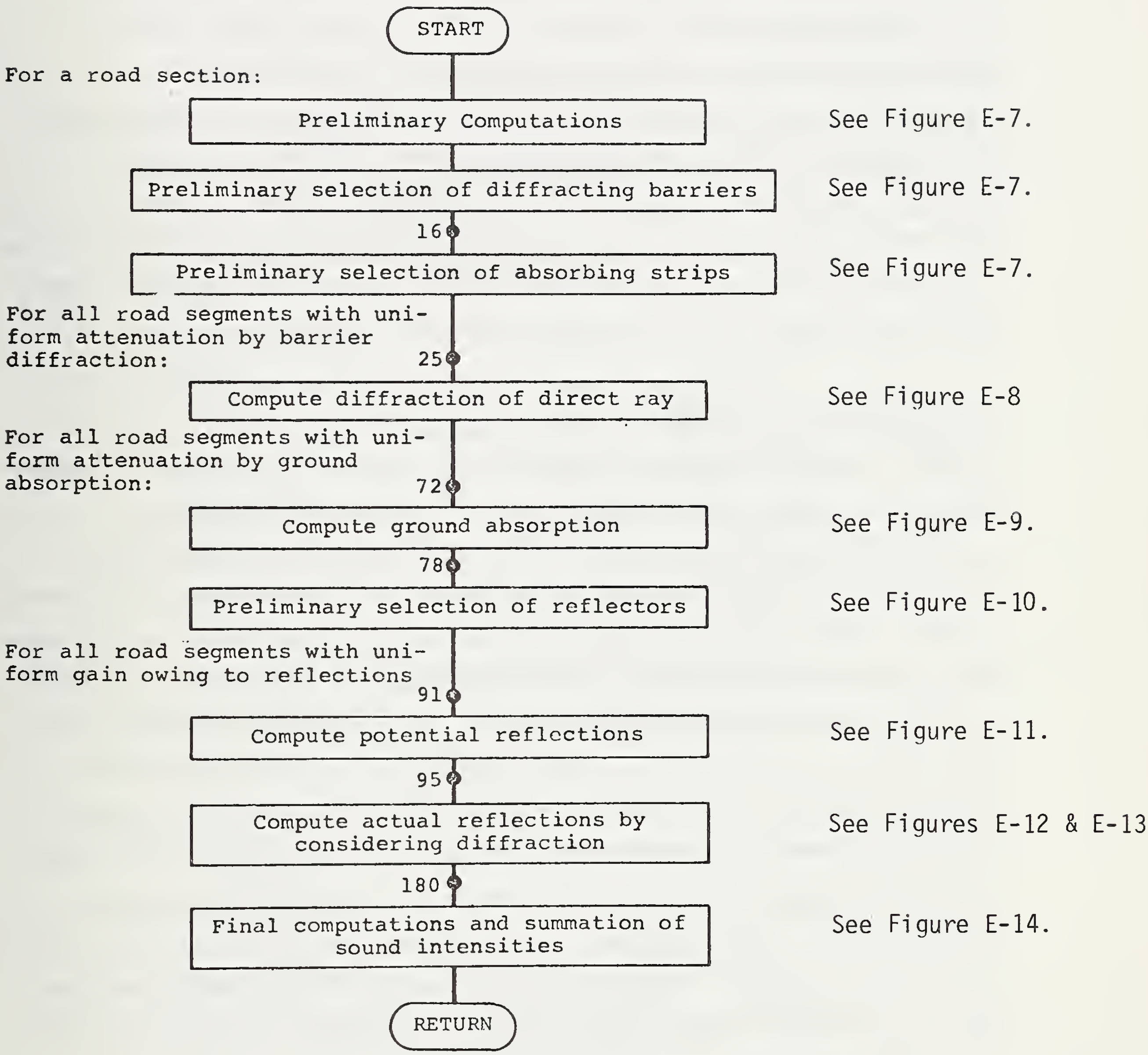


FIGURE E-6. SUBROUTINE GEOMRY: OVERVIEW

GEOMRY checks during the preliminary calculations to see if barrier segments and/or ground strip segments lie interior to the x-y plane projection of the roadway/receiver triangle. Using only x-y plane geometry, segments or portions of segments of barriers and/or ground strips are identified as "potential" diffractions or ground strips, respectively, which are stored for a more detailed analysis.

The detailed consideration of diffraction or ground strip attenuation is accomplished by GEOMRY using a sequential subdivision of the straight line roadway segment into subsegments, beginning at point XR10. If no barriers, ground strips, or reflectors have been encountered, no subdivision of the segment XR10, XR20 occurs and the acoustic intensity is calculated from the roadway segment. (Equation (A-3))

If a potential diffraction or ground strip has been encountered, the segment (XR10,XR20) is subdivided as indicated in Figure A-1 (c) as an example. For each subsegment potentially affected by a barrier, GEOMRY further subdivides the roadway segment using three-dimensional geometry to determine whether or not the diffraction is significant. For significant diffractions (See Equation(A-21))the roadway subdivision continues until uniform acoustic intensity at the receiver can be assumed. If a diffraction is encountered, GEOMRY ignores attenuation potentially resulting from absorptive ground strips for subsegment geometry. For each diffraction calculation, GEOMRY retains only the maximum path length difference calculated for each vehicle type (including source height adjustment) to estimate attenuation resulting from diffraction.

Subroutine GEOMRY checks first for diffraction, then for absorptive ground strips, and finally for reflections to establish the subdivision of a roadway segment. Hence, a roadway segment as defined by the user may be subdivided several times internaly by GEOMRY prior to returning to the MAIN PROGRAM.

Flow diagrams are presented in Figures E-7 through E-14 illustrating the detail operations and branches of the internal calculations utilized by

GEOMRY for each major consideration presented in Figure E-6. These flow diagrams are presented at the end of the subroutine description so as not to interrupt the flow of text. Statement numbers are shown so that the user may refer to blocks of code in the subroutine listing. The subroutine listing is presented following the flow diagrams.

Figure E-7 illustrates the preliminary calculations performed by GEOMRY. First, GEOMRY calls subroutine COLIN to insure that the receiver point and the roadway segment are not colinear. Next, GEOMRY calculates the distance, DIST, and the point on the line through the roadway segment end points, XNPT, using subroutine NRPT. The angle, ANG1 , between the normal from the receiver point to the roadway line and the line from the receiver point to the roadway end point, XR10, is calculated using subroutine ANGLE.

As indicated in Figure E-7, the preliminary selection of barriers is accomplished by calling subroutines DEGEN and BLOCN to determine if barrier segments occurr internally to the x-y plane triangle formed by the roadway segment and receivers. (See Figure E-2) If a potential barrier is encountered, barrier data is stored internally to GEOMRY. Otherwise, the barrier segment is ignored. All barrier segments are checked for each call to subroutine GEOMRY. The preliminary selection of absorptive ground strips is analogous to the procedure described for barriers.

Following the preliminary selection of barriers and ground strips, GEOMRY then begins the detail calculation of barrier diffraction. The flow diagram for these considerations is presented in Figure E-8. During this step in the computation the roadway segment being analyzed is subdivided to ensure that uniform reception of acoustic intensity at the receiver occurs (See Equation(A-21)). The path length difference is initialized to ensure that barrier attention is zero (DELPO=-0.2). This initialization corresponds to an octave band center frequency of 500 Hz. The subsegment of roadway being analyzed is carried internally as (XR1,XK).

GEOMRY bases the selection of significant barrier diffraction using the source height adjustment specified for automobiles and light trucks. Once the subdivision of the roadway has proceeded so that the criteria of Equation(A-21)has been satisfied, the path length difference for each vehicle type is computed. These values are compared with the maximum values of path length difference stored in array DELPO to ensure that the maximum value for the path length difference is retained. Hence, barrier attenuation is calculated by vehicle type using the maximum value of the path length difference encountered between the roadway subsegment and the receiver. This procedure allows consideration of only the most effective barrier in multi-barrier configurations (See Section A.6, Appendix A). The reader should be aware that the maximum path length difference may not correspond to the highest barrier but depends upon source location, barrier elevation, and receiver location.

Figure E-9 presents the flow diagram for the calculation of sound level attenuation resulting from ground absorption. If significant diffraction has been encountered for the roadway subsegment under analysis, GEOMRY disregards the attenuation resulting from a ground strip and proceeds to the consideration of reflections. Further, if the direct ray path from the source roadway subsegment to the receiver passes above the top of the ground strip (10 feet above ground elevation for shrubbery, 30 feet for trees) the attenuation due to the ground strip is disregarded. If GEOMRY determines that ground strip attenuation is significant, the attenuation is calculated as described in Section A.7, Appendix A.

Figure E-10 presents the flow diagram for the preliminary selection of reflectors in GEOMRY. By the introduction of an image receiver location, the reflection problem becomes similar to the diffraction problem. A reflector in the path from the road segment to an image receiver is effective whenever a barrier in the path from the road segment to a receiver strongly diffracts the sound.

Also, the intensity of the direct (or diffracted) sound from the road segment considered is compared to the potential maximum contribution of each reflection. This check assures that only essential reflectors are considered. Since a reflector might not be high enough or reflections might be strongly attenuated by diffraction at additional barriers in the ray path, the reflectors found at this stage are considered "potential" reflectors.

During the preliminary selection of reflectors GEOMRY also conducts the preliminary selection of barriers which can possibly diffract the reflected sound. The check performed is based on the length and orientation of a barrier section and on the distance from the image receiver relative to the respective parameters of the road section and the receiver considered.

Figure E-11 is the flow diagram for the block of code in GEOMRY that considers barrier elevation as related to potential reflection of sound. If the height difference above the reflector of a sound ray from the nearest point on the road segment leads to the acceptance or rejection of the reflector, no further check is made for other source points on the road segment.

Since diffraction of the reflected ray is not yet checked, a reflection is still called a potential one and the end point of the road segment is preliminary. As the final step in the reflector problem, GEOMRY considers possible diffraction both before reflection and after reflection.

Figure E-12 presents the flow diagram for consideration of diffraction before reflection. Checks for barriers in the area defined by projections of the four points XR1, XR2, XRB3, and XRB4 into the x-y plane are made by considering first the triangle containing image rays and then the triangle formed by the road segment and the image receiver.

If a barrier is found to be high enough for possible diffraction, the reflector is checked again to determine whether or not it is

high enough to reflect the diffracted rays (which now come from an effective source that might by considerably higher than the roadway).

Calculation of the path length difference between diffracted and direct rays from only the near point of the road segment implies that the diffraction of sound rays from other source points is about the same.

Very strongly diffracted reflections are neglected. The decision is made on the basis of the diffraction of sound from trucks, since rays from cars are even more strongly diffracted.

Figure E-13 presents the flow diagram for the consideration of diffraction after reflection. Checks are made for diffracting barriers in the triangle defined by projections of the reflector segment (XRB3, XRB4) and the receiver XRC onto the x-y plane.

After a barrier has been found which is high enough for possible diffraction, the reflector is checked to determine whether or not it is high enough to reflect sound towards the top line of the diffracting barrier, which might be considerably higher than the receiver.

Calculation of the path length difference implies simplifying assumptions similar to those for the problem of diffraction before reflection.

Reflections are neglected in the case of diffraction before and after reflection and in the case of very strong diffraction after reflection.

Figure E-14 presents the flow diagram representing the block of code in GEOMRY that performs the final computations and accumulation of sound intensities at the receiver. These calculations consider barrier diffraction, reflections (gain of direct sound), atmospheric absorption, and ground absorption. The calculations are directly related to the expression given in Appendix A, Equation (A-11) for the acoustic intensity. For the octave band center frequency of 500 Hz, the cumulant, κ_2, of the acoustic intensity is calculated (See Equation A-35) and accumulated.

After the calculation and accumulation of acoustic intensity, GEOMRY checks to see if the subsegment end point XR2 is within a prescribed distance to the end points of the subsegments defining the segment end point XR20, or the subsegment end point XR2G corresponding to a ground strip, or a subsegment end point XR2D corresponding to a diffraction. GEOMRY branches internally to continue the roadway segment analysis until the point XR2 is within 1 foot of the segment end point XR20. When this criteria is satisfied, GEOMRY returns control to the MAIN program.

SUBPROGRAMS REQUIRED

See Figure D-1, page D-2.

VARIABLES

Due to the lengthly and complex nature of subroutine GEOMRY, variables are listed in alphabetical order.

A	Atmospheric attenuation factor, ground absorption parameter
ADST	ANG/DIST
ANG	Angle subtended at receiver by road segment
ANG1	Angle α_1 in Fig. A-1
ANG2	Angle α_2 in Fig. A-1
ANGI	Angle subtended at image receiver by road segment
ANGIMG	Angle subtended at image receiver by barrier section
B1	End point of barrier section
BGS	Width of absorptive ground strip
BGT	Width of absorptive ground strip
BX	x-coordinate of barrier point
BY	y-coordinate of barrier point
BZ	z-coordinate of barrier point
CA1	$\cos(\alpha_1)$

CA2 $\cos(\alpha_2)$

CPREV Angular function C_{n-1}, defined in Equation (A-35)

CQ Factor accounting for standard deviation of reference level

DELM Mean path length difference

DELP Path length difference

DELPØ Maximum path length difference for diffraction of direct ray

DELP1 Maximum path length difference for diffraction before reflection

DELP2 Maximum path length difference for diffraction after reflection

DELPA Path length difference for diffraction of direct ray

DELR Path length difference for reflected ray

DELTA Distance along the roadway

DIST Distance from the receiver to the source line

DISTI Distance from the image receiver to the source line

DISTJ Distance from the image receiver to the diffracting barrier

DL Mean path length over an absorptive ground strip

DN1 Distance from the receiver to the nearest point of the road segment

DN1I Distance from the image receiver to the nearest point of the road segment

DN2 Distance from the image receiver to the nearest point of the diffracting barrier

DR1 Distance from the receiver to the initial point of the road segment

DRK Distance from the receiver to the preliminary end point of the road segment

FB Attenuation factor accounting for diffraction and reflections

FCTR Weighting factor for reflections

FG	Ground attenuation factor
HDIFA	Height of ray from source point XR1 to receiver XRC above barrier
HDIFF	Height of ray above barrier, reflector, or ground strip
HGA	Data for effective height of ground cover
I	Index
IA	Alphanumeric "A"
IBAR	Barrier number
IBLAST	Barrier type
ICODE	Number for intermediate printout
IDUM	Index for kind of absorptive ground cover
IDXR	Number of reflections
IERR	Error index
IGRA	Ground strip number
IF	Index for frequency bands
II	Index
IK	Frequency band number
IKIN	Index for kind of absorptive ground cover
IP	Frequency band number
IQ	Index
IR	Alphanumeric "R"
ISEG	Barrier section number
IT3	2N - 1
ITRIG	Trigger
KAR	Alphanumeric indicator for type of barrier
KBAR	Total number of barrier sections; index for barriers
KBAR1	Reflector number in storage
KBAR2	Diffractor number in storage

KBCODE	Indicator for relative location of barrier
KCD	Indicator for relative location of barrier
KDIFF	Barrier number in storage
KF	Index for frequency bands
KGA	Number of ground strips stored
KGCODE	Indicator for relative location of ground strip
KIMG	Reflection number
KNUMB	Total number of relevant barrier sections
KREF	Reflector number stored
KRDNUM	Total number of barrier sections relevant to reflection
KRFDF	Barrier number stored
KRNUM	Total number of relevant reflector sections
KTRIG	Indicator for intersection of barrier or ground strip
LOC	Indicator for relative location of barrier or ground strip
MDIFF	Indicator for diffraction before reflection
MODD	Indicator for diffraction of direct ray
MR	Roadway number
N	Cumulant numbers
NB	Number of barriers
NBSEC	Number of barrier sections
NBSM1	Number of sections for one barrier
NDIFF	Number of barriers stored
NF	Number of frequency bands
NG	Number of absorptive ground strips
NIMG	Number of reflections
NLIM	Number of points defining one barrier
NQ	Number of vehicle types

NQQ	Number of groups within one vehicle type
NQS	Vector notation for number of vehicle groups
NR	Number of roadways
NREF	Number of reflectors stored
NRFDF	Number of barriers stored
PP	Frequency band number
R1	End point of potential reflector
RATIO	Weighting factor for reflected rays
RB1	End point of barrier in path of reflected ray
RDIN	Vector notation for initialization parameters
SA1	$\sin(\alpha_1)$
SA2	$\sin(\alpha_2)$
T1	Temporary variable
T2	Temporary variable
T3	Temporary variable
TA1	End point on center line of absorptive ground strip
VEXPH	Vehicles per foot
XB1	Initial point of barrier stored
XB2	End point of barrier stored
XDB1	Initial point of barrier stored
XDB2	End point of barrier stored
XDB3	Initial point of effective barrier segment
XDB4	End point of effective barrier segment
XG1	Initial point of center line of absorptive ground strip
XG2	End point of center line of absorptive ground strip
XG3	Initial point of effective ground strip segment
XG4	End point of effective ground strip segment
XIMG	Vector of image receivers for all reflections

XJ	Preliminary end point of effective reflector segment
XK	Preliminary end point of road segment
XKA	Cumulant of the A-weighted sound intensity
XKI	Preliminary end point of image road segment
XLA	A-weighted intensity in frequency bands
XLE	Mean intensity
XLREF	Vector notation for reference intensities
XN1	Point on road segment nearest to receiver
XN1I	Point on road segment nearest to image receiver; point on image road segment nearest receiver
XN2	Point on barrier segment nearest to image receiver
XNPT	Point on source line nearest to receiver
XNPTI	Point on source line nearest to image receiver
XNPTJ	Point on image source line nearest receiver
XR	X-coordinate of receiver
XR1	Initial point of road segment
XR1Ø	Initial point of road section
XR1I	Initial point of image road segment
XR2	End point of road segment
XR2Ø	End point of road section
XR2D	End point of road segment with constant attenuation by diffraction
XR2G	End point of road segment with constant attenuation by ground absorption
XR2I	End point of image road segment
XRB1	Initial point of reflector stored
XRB2	End point of reflector stored
XRB3	Initial point of effective reflector segment
XRB4	End point of effective reflector segment

XRC	Receiver point
XRCI	Image receiver point
XXG1	X-coordinate of point on ground strip center line
YR	Y-coordinate of receiver
YYG1	Y-coordinate of point on ground strip center line
ZN1Ø	Z-coordinate of XN1 or XN1I
ZR	Z-coordinate of receiver
ZS	Height adjustment for vehicles
ZZG1	Z-coordinate of point on ground strip center line

RESTRICTIONS

Due to the complex nature of subroutine GEOMRY, the user should use caution in attempting modifications. Changes in the direct calculation schemes related to the acoustic models assumed are found in the following lines of code:

Calculation of Ground Absorption: Lines 160 to 173
Calculation of Barrier Attenuation: Lines 326 to 338
Calculation of Reflection Gain: Lines 340 to 352
Calculation of Normalized Mean Intensity and Dispersion
  of Mean Intensity: Lines 356 to 381
Calculation of Atmospheric Absorption: Line 364.

Note: If the user desires to modify the barrier model described in this manual, he is warned to check subroutine GEOMRY thoroughly as several important criteria required for decisions concerning the accumulation of uniform acoustic intensity at a receiver are affected. Similarly, the user should not attempt to blindly alter the code for dimensions in metric units without appropriate modification of GEOMRY and other subprograms.

ACCURACY

Dependent upon the acoustic models utilized in the problem formulation.

SIZE

17624_8

REFERENCES

See Appendix A of this manual.

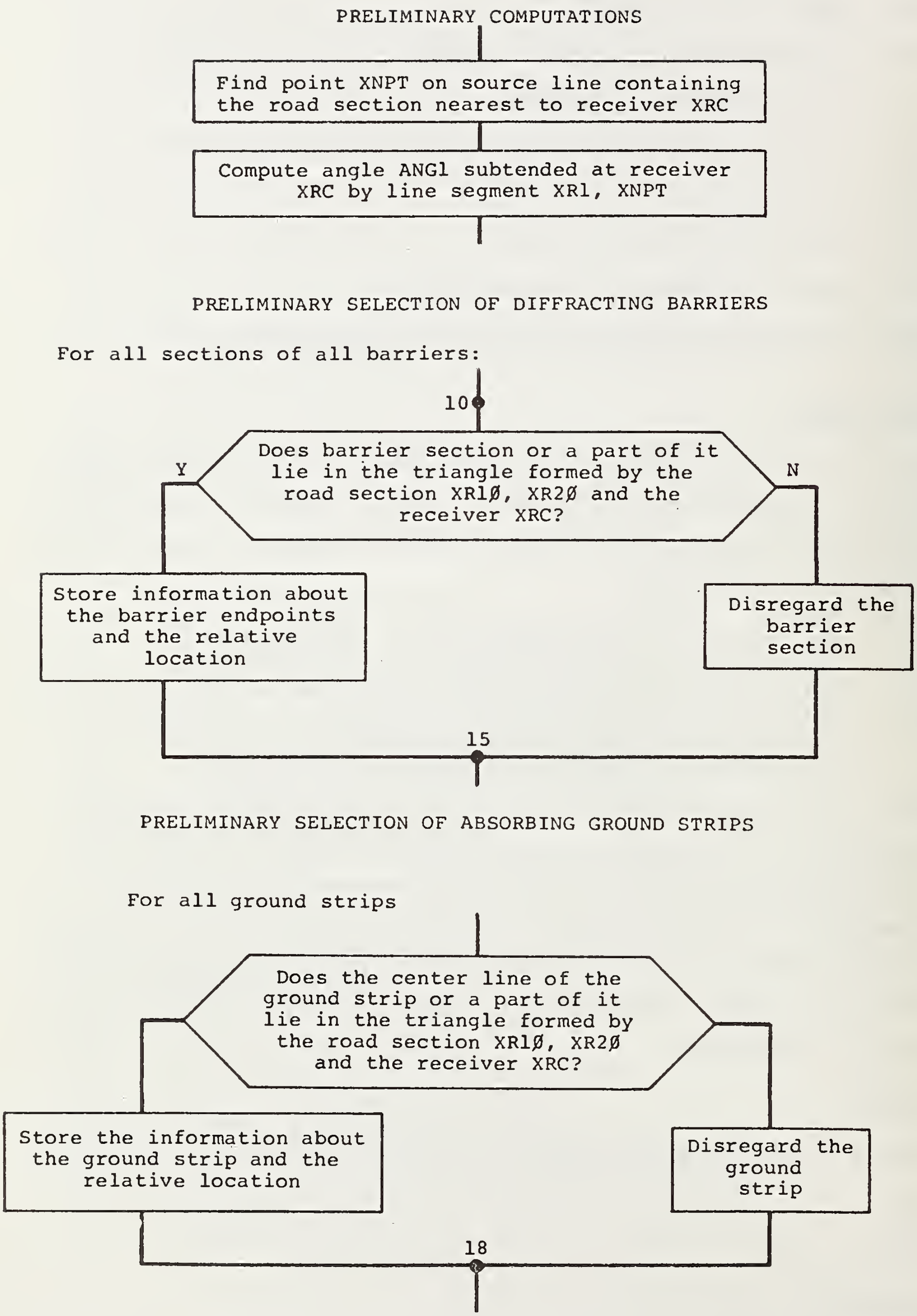


FIGURE E-7. SUBROUTINE GEOMRY: FLOW DIAGRAM OF PRELIMINARY OPERATIONS

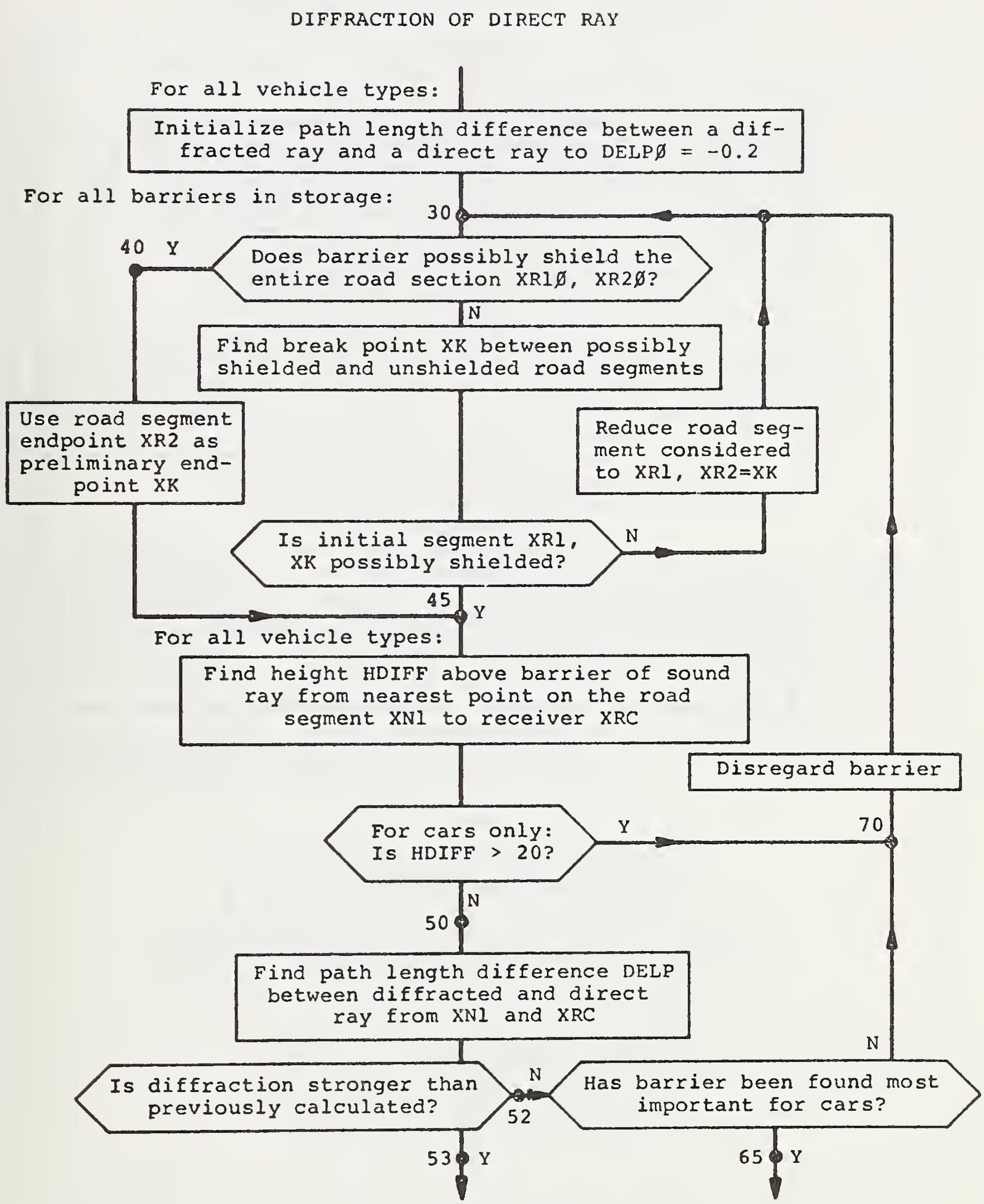


FIGURE E-8. SUBROUTINE GEOMRY: FLOW DIAGRAM OF BARRIER DIFFRACTION CONSIDERATIONS FOR THE DIRECT RAY (Continued)

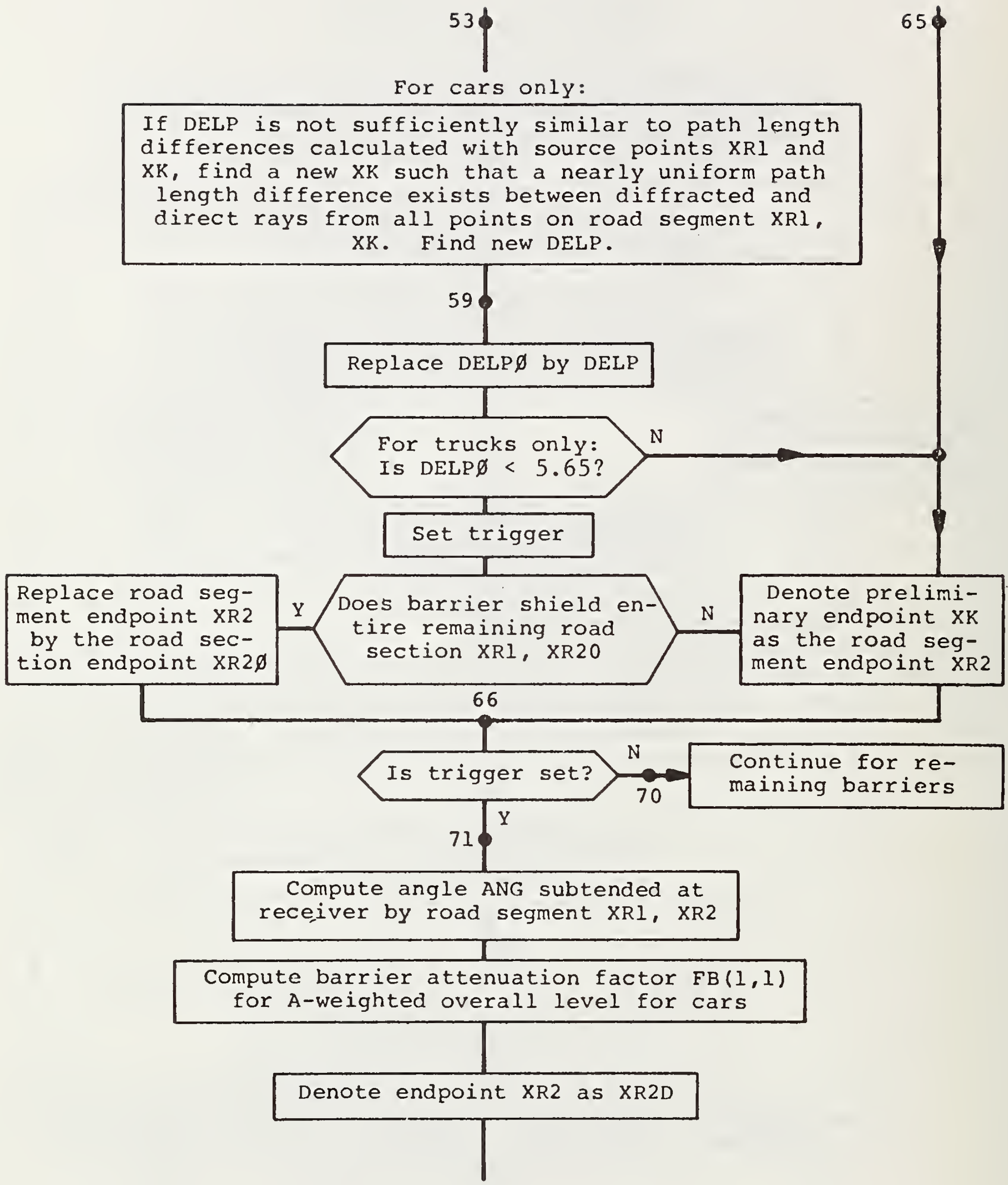


FIGURE E-8. (Concluded)

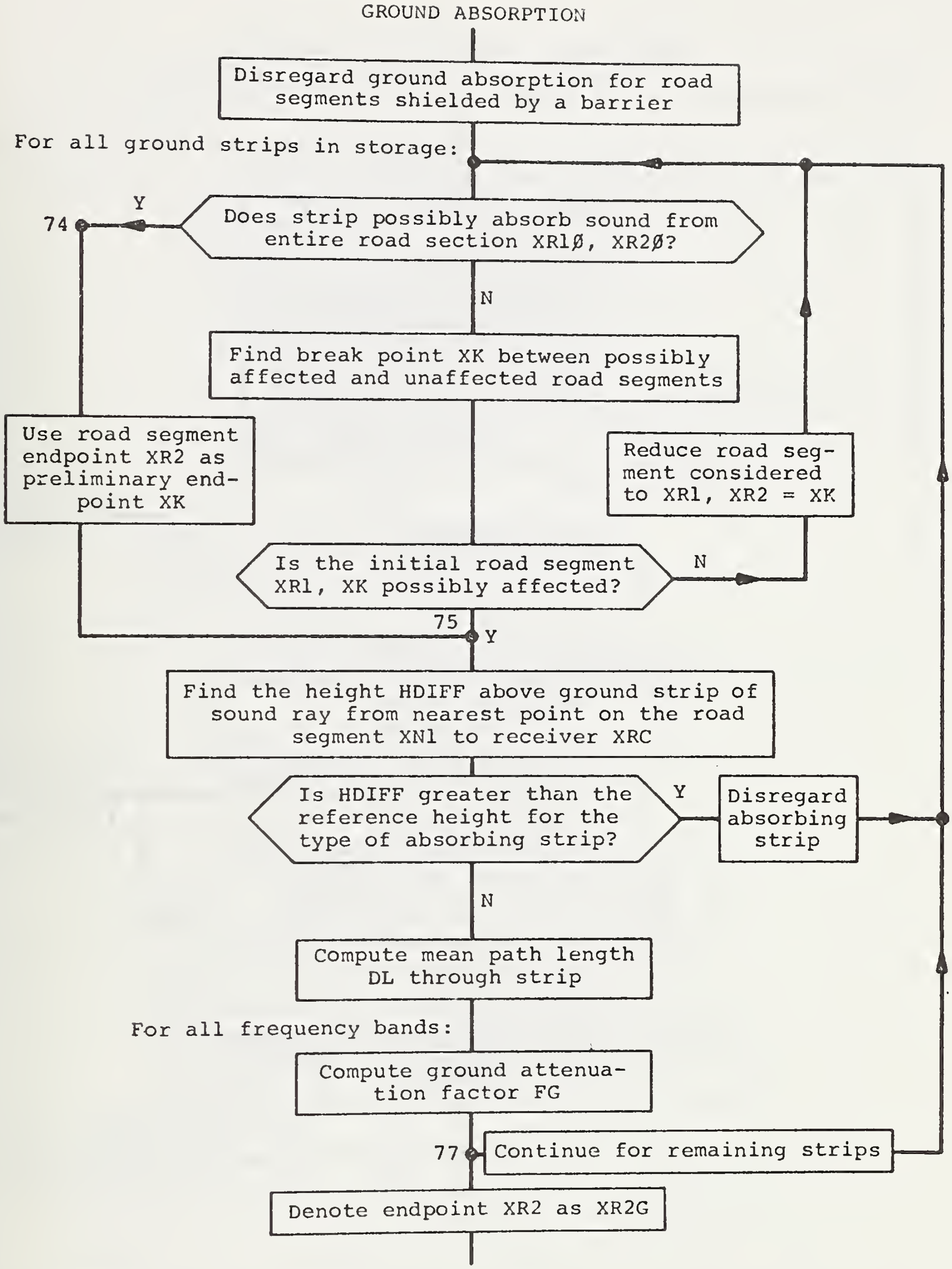


FIGURE E-9. SUBROUTINE GEOMRY: FLOW DIAGRAM OF ABSORPTIVE GROUND STRIP CONSIDERATIONS

PRELIMINARY SELECTION OF REFLECTORS

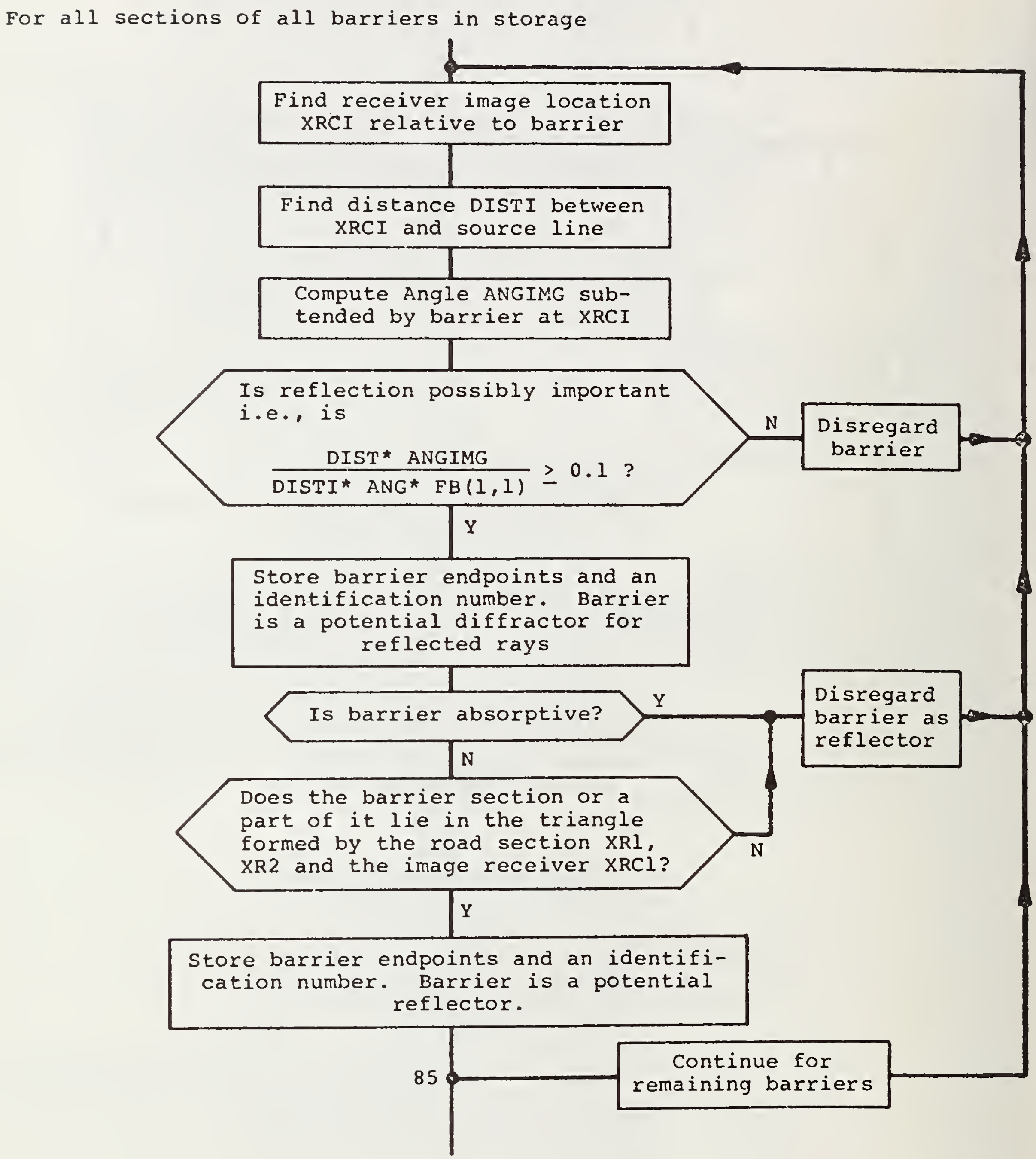


FIGURE E-10. SUBROUTINE GEOMRY: FLOW DIAGRAM FOR THE PRELIMINARY SELECTION OF REFLECTORS

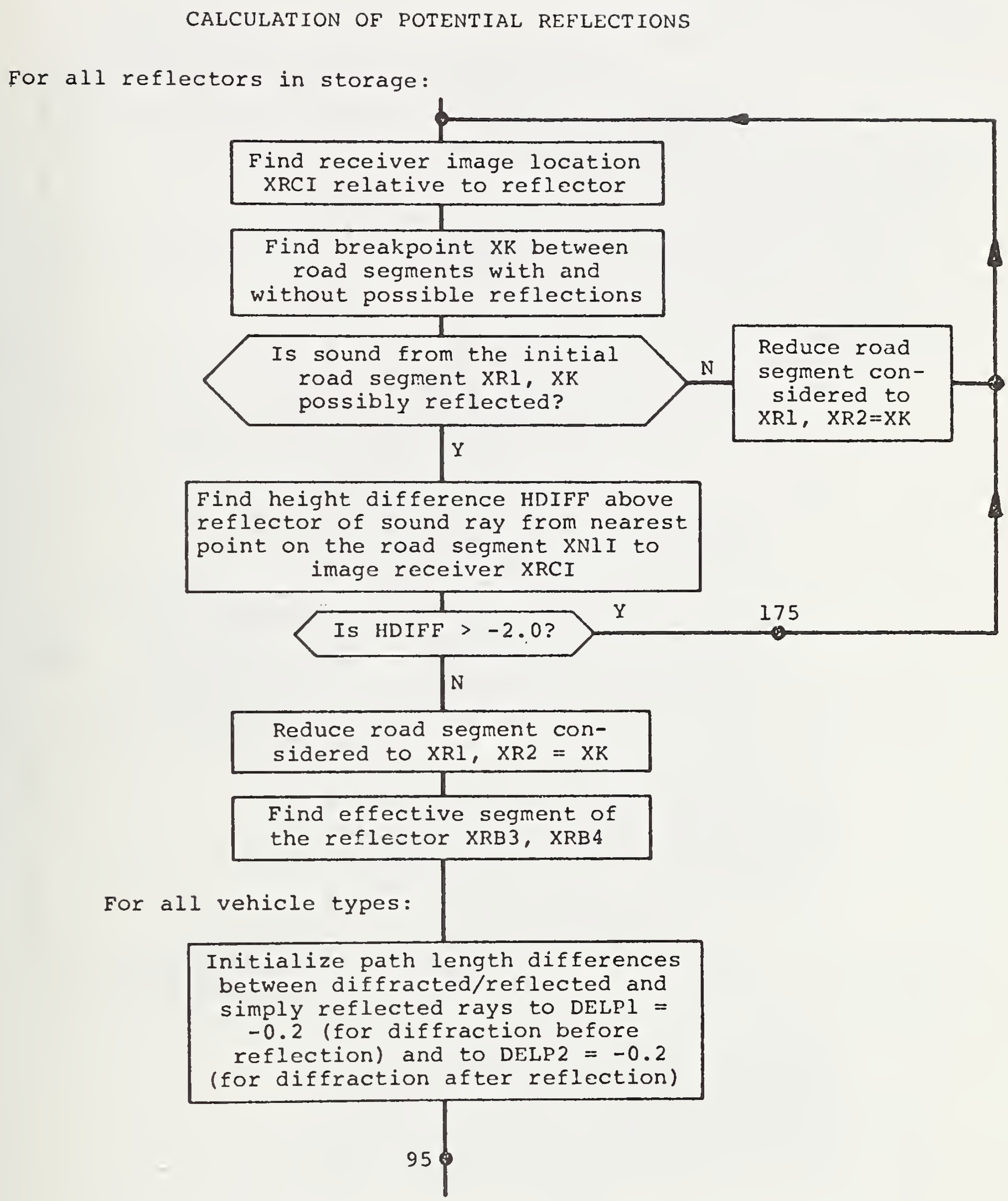


FIGURE E-11. SUBROUTINE GEOMRY: FLOW DIAGRAM FOR CALCULATION OF POTENTIAL REFLECTIONS

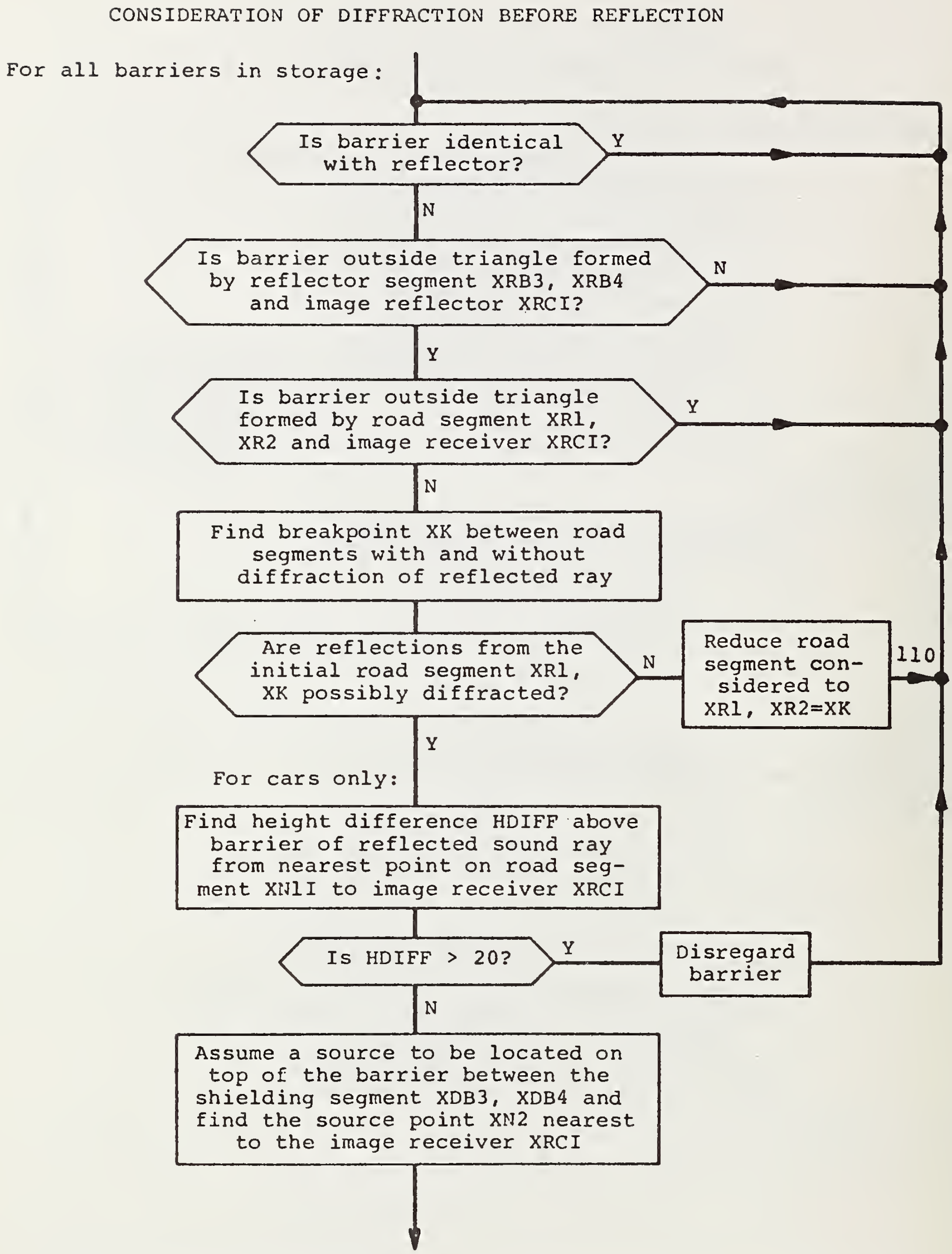


FIGURE E-12. SUBROUTINE GEOMRY: FLOW DIAGRAM FOR CONSIDERATION OF DIFFRACTION BEFORE REFLECTION (Continued)

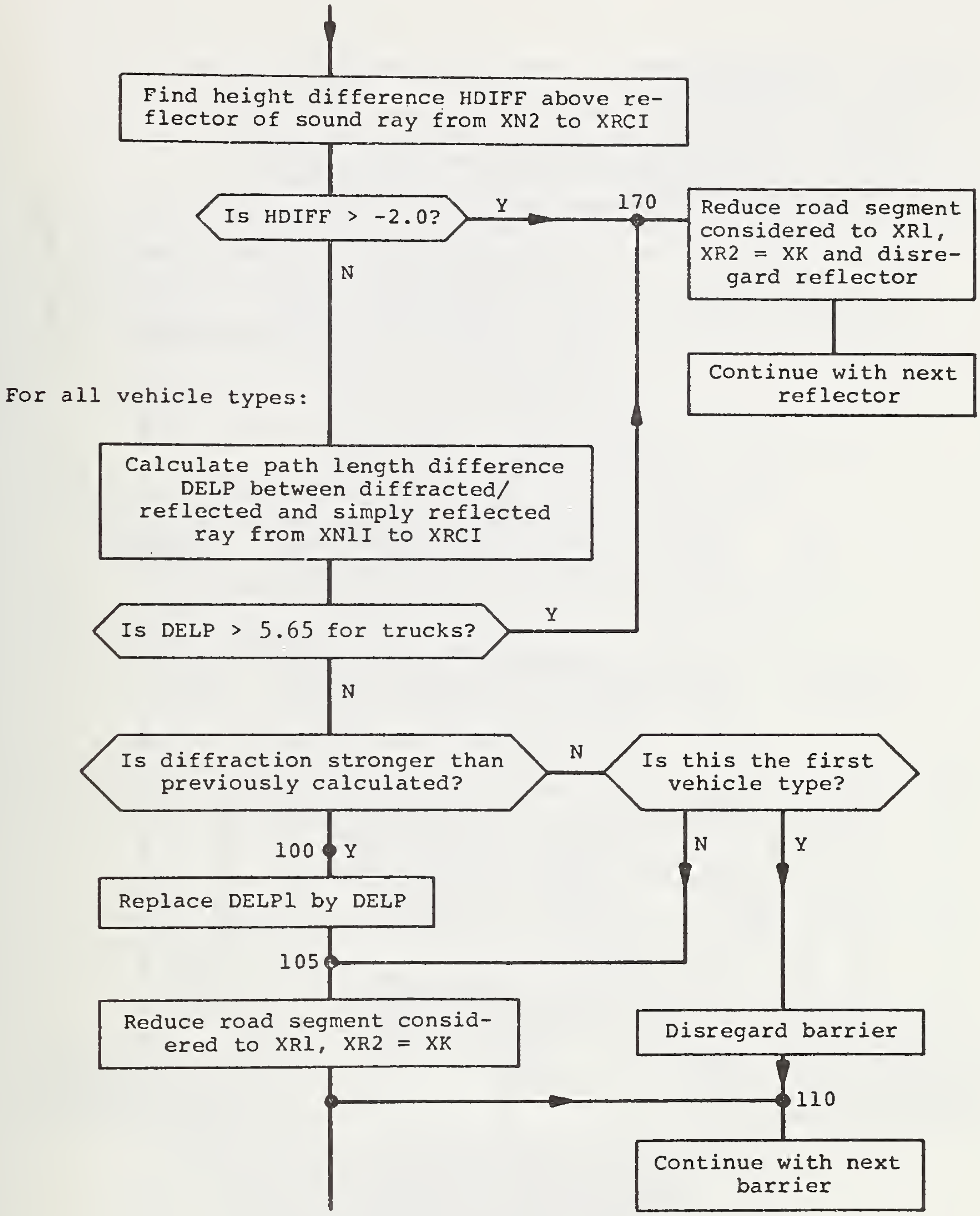


FIGURE E-12. (Concluded)

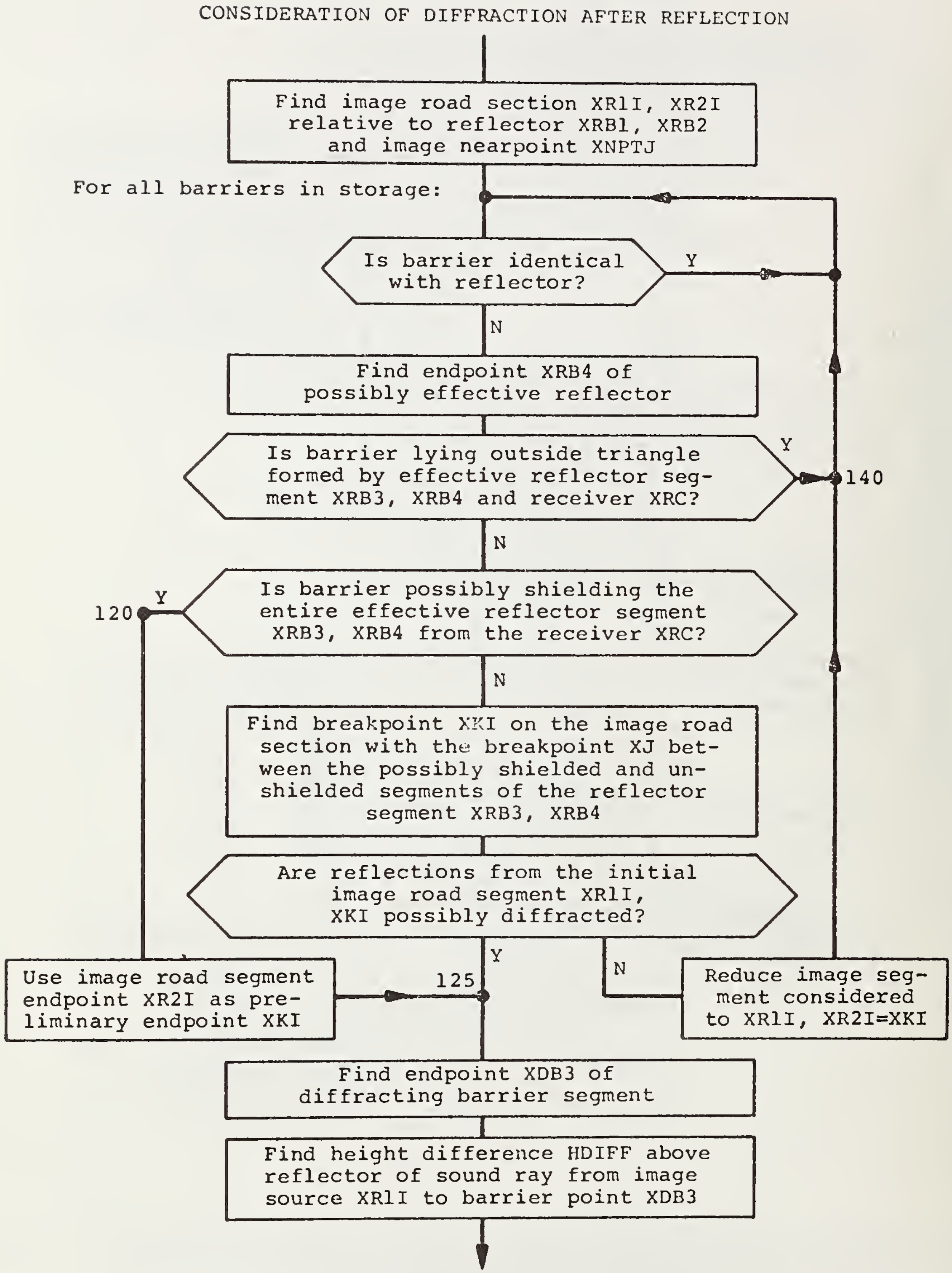


FIGURE E-13. SUBROUTINE GEOMRY: FLOW DIAGRAM FOR CONSIDERATION OF DIFFRACTION AFTER REFLECTION (Continued)

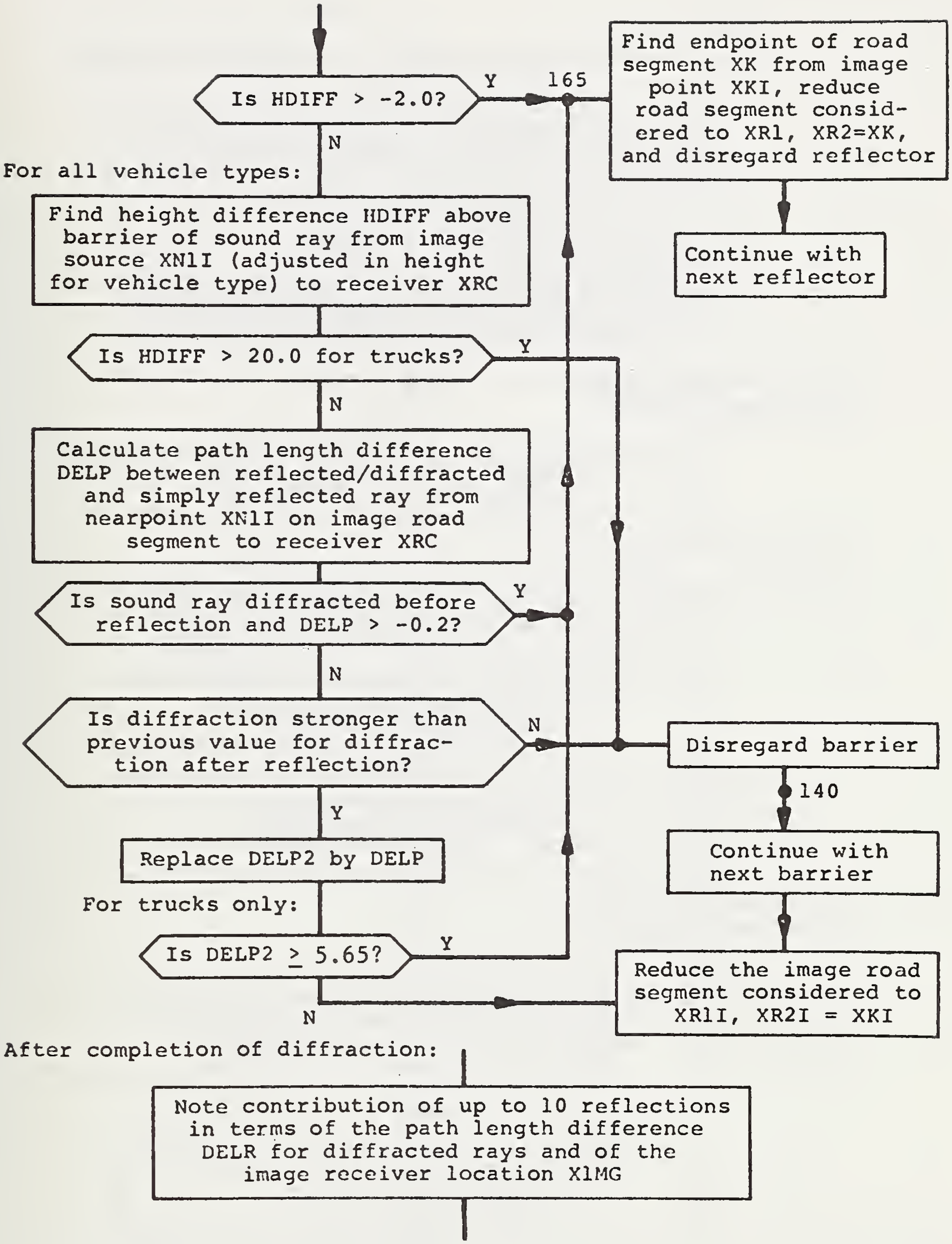


FIGURE E-13. (Concluded)

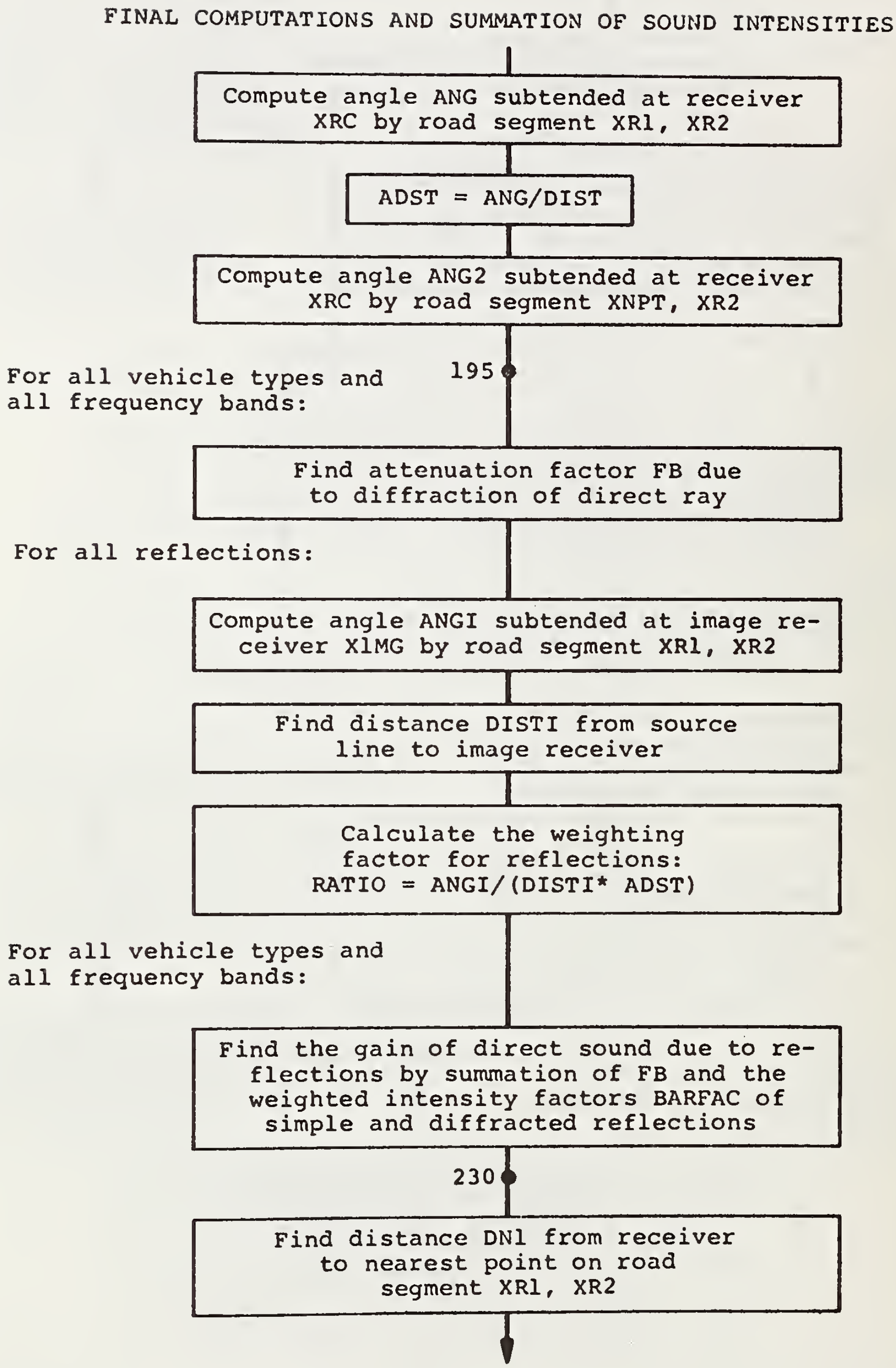


FIGURE E-14. SUBROUTINE GEOMRY: FLOW DIAGRAM FOR FINAL CALCULATION AND SUMMATION OF SOUND INTENSITIES (Continued)

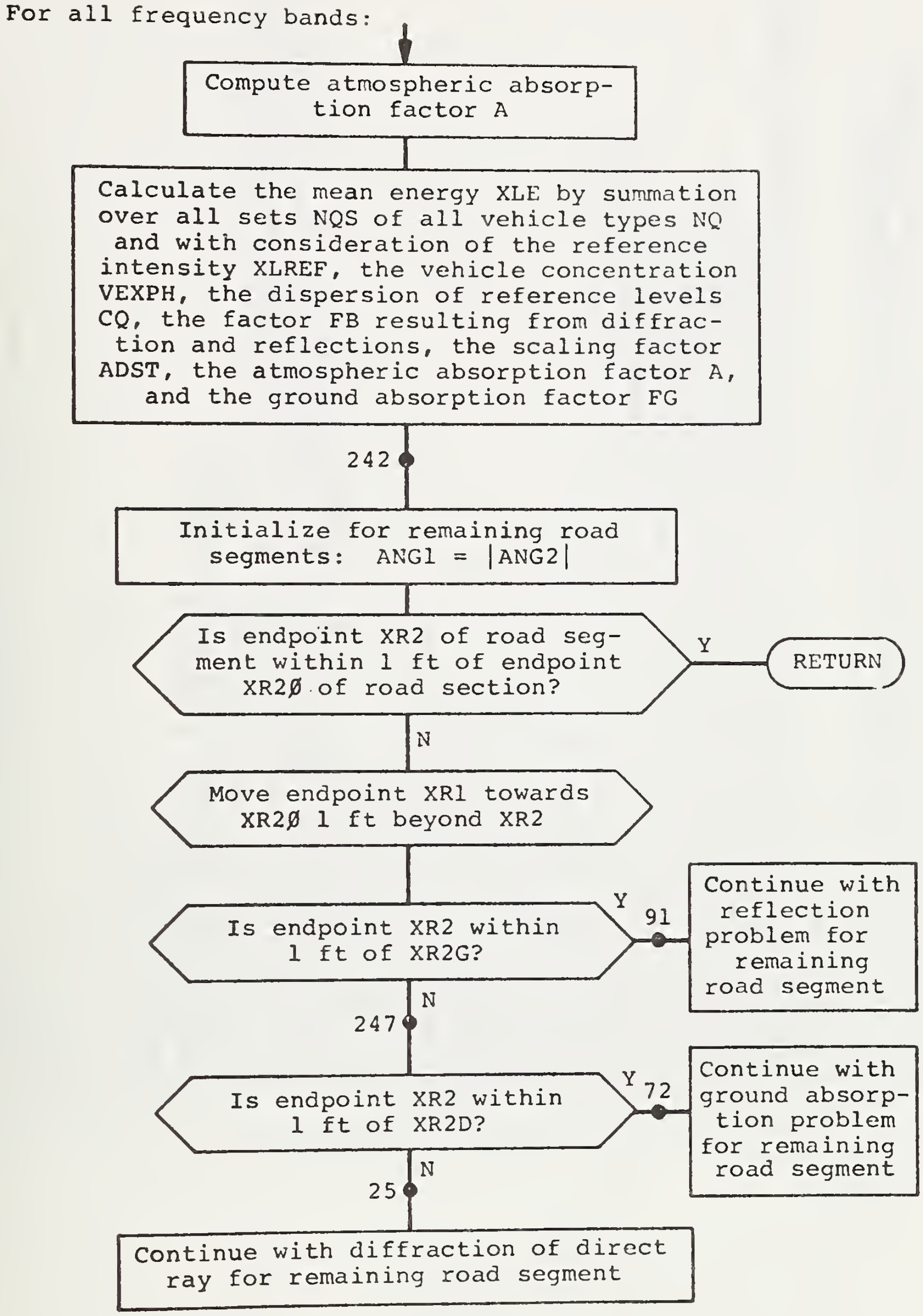


FIGURE E-14. (Concluded)

```
C   GEOMETRY ROUTINE
      SUBROUTINE GEOMRY(XR,YR,ZR,XR10,XR20,IERR,MK)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION XG1(3),XG2(3),XG3(3),XG4(3)
      DIMENSION B1(3,2,20),R1(3,2,20),RB1(3,2,20),TA1(3,2,20)
      DIMENSION KBCODE(20),KNUMB(20),KRNUMB(20),KRDNUM(20)
      DIMENSION KGCODE(10),BGT(10),IKIN(10)
      DIMENSION
     D DELP0(4),DELP1(4),DELP2(4),FB(9,4),DELR(4,10),FG(9),HGA(2),
     X XB1(3),XB2(3),XDB1(3),XDB2(3),XDB3(3),XDB4(3),
     X XRB1(3),XRB2(3),XRB3(3),XRB4(3),XRC(3),XRCI(3),
     X XR1(3),XR2(3),XR11(3),XR21(3),XR10(3),XR20(3),
     X XK(3),XKI(3),XJ(3),XNPT(3),XNPTI(3),XNPTJ(3),
     X XN1(3),XN2(3),XN11(3),XIMG(3,10),XR2D(3),XR2G(3),
     Z ZS(4)
      DIMENSION XH1(3)
      COMMON/INOU/INPT,IOUT
      COMMON/BLK2/NQ
      COMMON /INPT1/RDIV(6)
      COMMON/INPT2/NR,NB,NG
      COMMON/DRIV2/NQS(20,4),NF
      COMMON /DRIV3/XLE(9)
      COMMON/DRIV4/CAP2
      COMMON/STORE4/XMPH(20,5,4),VEXPH(20,5,4)
      COMMON/STORE1/BX(20,11),BY(20,11),BZ(20,11),IBLAST(20),NBSM1(20)
      COMMON/STORE2/XXG1(10,2),YYG1(10,2),ZZG1(10,2),BGS(10),IDJM(10)
      COMMON/GEO1/IBAR,ISEG,IGRA
      COMMON /INTFR1/XLREF(3600),CQ(3600)
      EQUIVALENCE (RDIN(3),ZS(1))
      DATA   IR/2HR /
      DATA HGA(1),HGA(2)/10.,30./
      XRC(1)=XR
      XRC(2)=YR
      XRC(3)=ZR
      IERR=0
      CALL COLIN(XR10,XR20,XRC)
      CALL VRPT(XR10,XR20,XRC,XNPT,DIST)
      ANG1=ANGLE(XR10,XNPT,XRC)
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
C       ICODE=1
C       WRITE(IOUT,1000)ICODE,XR10,XR20,XRC,XNPT
C PRELIMINARY SELECTION OF BARRIERS
        NDIFF=0
        IF(NB.EQ.0) GO TO 16
        KBAR=0
        DO 15 IBAR=1,NB
        KAR=IBLAST(IBAR)
        XB1(1)=BX(IBAR,1)
        XB1(2)=BY(IBAR,1)
        XB1(3)=BZ(IBAR,1)
        NLIM=NBSM1(IBAR)+1
        DO 15 ISEG=2,NLIM
        XB2(1)=BX(IBAR,ISEG)
        XB2(2)=BY(IBAR,ISEG)
        XB2(3)=BZ(IBAR,ISEG)
        KBAR=KBAR+1
C       ICODE=2
C       WRITE(IOUT,1001)ICODE,KBAR,XB1,XB2
     10 CALL DEGEN(XR10,XR20,XRC,XB1,XB2,LOC)
        IF (LOC EQ 5) CALL BLOCN(XR10,XR20,XRC,XB1,XB2,XK,LOC)
     11 IF(LOC EQ.0)GO TO 12
        NDIFF=NDIFF+1
        KNUMB(NDIFF)=KBAR
        KBCODE(NDIFF)=LOC
        CALL REPLCE(XB1,B1(1,1,NDIFF))
        CALL REPLCE(XB2,B1(1,2,NDIFF))
     12 CALL REPLCE(XB2,XB1)
     15 CONTINUE
C PRELIMINARY SELECTION OF STRIPS
     16 KGA=0
        IF(NG.EQ.0)GO TO 20
        DO 18 IGRA=1,NG
        XG1(1)=XXG1(IGRA,1)
        XG1(2)=YYG1(IGRA,1)
        XG1(3)=ZZG1(IGRA,1)
        XG2(1)=XXG1(IGRA,2)
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
      XG2(2)=YYG1(IGRA,2)
      XG2(3)=ZZG1(IGRA,2)
C     ICODE=3
C     WRITE(IOUT,1001)ICODE,IGRA,XG1,XG2
   17 CALL DEGEN(XR10,XR20,XRC,XG1,XG2,LOC)
      IF(LOC.NE.5) GO TO 1701
      CALL BLOCN(XR10,XR20,XRC,XG1,XG2,XK,LOC)
 1701 IF(LOC.EQ.0)GO TO 18
      KGA=KGA+1
      KGCODE(KGA)=LOC
      CALL REPLCE(XG1,TA1(1,1,KGA))
      CALL REPLCE(XG2,TA1(1,2,KGA))
      BGT(KGA)=BGS(IGRA)
      IKIN(KGA)=IDUM(IGRA)
   18 CONTINUE
C DIFFRACTION OF DIRECT RAY
   2  CALL REPLCE(XR10,XR1)
   25 CALL REPLCE(XR20,XR2)
      CALL REPLCE(XR1,XH1)
      DO 30 IQ=1,NQ
      DELPC(IQ)=-.2
   30 CONTINUE
C     ICODE=4
C     WRITE(IOUT,1000)ICODE,XR1,XR2
       IF(NDIFF.EQ.0)GO TO 71
      ITRIG=0
      DO 70 KDIFF=1,NDIFF
      KBAR=KNUMB(KDIFF)
      KCD=KBCODE(KDIFF)
      CALL REPLCE(B1(1,1,KDIFF),XB1)
      CALL REPLCE(B1(1,2,KDIFF),XB2)
C     ICODE=5
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
C     WRITE(IOUT,1001)ICODE,KBAR,XR1,XR2,XB1,XB2
      IF(KCD EQ.3)GO TO 40
      CALL ENDPT(XR1,XR2,XRC,XB1,XB2,XK,KTRIG,IERR)
      IF(IERR.EQ.4) RETURN
      IF(KTRIG.EQ.0)GO TO 70
      GO TO 45
   40 CALL REPLCE(XR2,XK)
   45 MODD=0
C     ICODE=6
C     WRITE(IOUT,1001)ICODE,KCD,XR2,XK
      DO 60 IQ=1,NQ
      CALL NR1(XR1,XK,XRC,XNPT,DIST,XN1,DN1)
      XN1(3) = XN1(3) + ZS(IQ)
      XH1(3) = XR1(3) + ZS(IQ)
      DN1 =AMAG(XRC,XN1)
      HDIFF=HEIGHT(XN1,XRC,XB1,XB2)
      IF(IQ.NE.1)GO TO 50
      IF(HDIFF GT 2..)GO TO 70
   50 DELP=DEL(XN1,XRC,XB1,XB2,HDIFF,DN1)
      IF(DELP.GT.DELPO(IQ))GO TO 53
   52 IF(MODD.EQ.1)GO TO 65
      GO TO 70
   53 IF (IQ NE.1) GO TO 59
      DR1 = AMAG(XRC,XH1)
C  ADJUST ELEVATION OF XK
      XK(3) = XK(3) + ZS(IQ)
      IF (DABS(DR1-DN1) LT.1.) GO TO 54
      HDIFA = HEIGHT(XH1,XRC,XB1,XB2)
      DELPA = DEL(XH1,XRC,XB1,XB2,HDIFA,DR1)
      DELM= (DELPA + DELP)/2.
C     ICODE=1 7
C     WRITE(IOUT,1000)ICODE,DELP,DELPA
      IF ((DABS(DELPA-DELP)-0.1-DELM/50.*(1.+DELM)).LE.0.) GO TO 55
      CALL MIDP(XH1,XN1,XK)
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
C       ICODE=7
C       WRITE(IOUT,1000)ICODE,XR1,XN1,XK
        DELP = DELPA
     54 IF (IEPS(XK,XRC,XB1,XB2,DELP) EQ.0) GO TO 58
        CALL MIDP(XH1,XK,XK)
C       ICODE=8
C       WRITE(IOUT,1000)ICODE,XR1,XK
        GO TO 54
     55 DRK= AMAG (XRC,XK)
        IF (DABS(DRK-DN1).LT.1.) GO TO 58
     56 IF(IEPS (XK,XRC,XB1,XB2,DELP).EQ.0) GO TO 58
        CALL MIDP(XN1,XK,XK)
        GO TO 56
C   READJUST XK TO GROUND LEVEL
  58    XK(3) = XK(3)-ZS(IQ)
        IF (DELP LE DELPO(1)) GO TO 52
     59 DELPO (IQ) = DELP
C       ICODE=10
C       WRITE(IOUT,1000)ICODE,DELPO(1),DELPO(2)
        MODD=1
      6 CONTINUE
        IF(DELPO(2) LT 5.65)GO TO 65
        ITRIG=1
        IF(KCO.NE.3.OR.KCO.NE.2)GO TO 65
        CALL REPLCE(XR2 ,XR2)
        GO TO 66
     65 CALL REPLCE(XK, XR2)
     66 IF(ITRIG.EQ.1)GO TO 71
     70 CONTINUE
C       ICODE=11
C       WRITE(IOUT,1000)ICODE,XR2
     71 ANG=ANGLE(XR1,XR2,XRC)
        IF (ANG.LT.0.01D-05) WRITE (IOUT,9C01) XR1,XR2,XRC
        DELP=DELPO(1)
        FB(1,1)=BARFAC(1,DELP)
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
C         ICODE=12
C         WRITE(IOUT,1002)ICODE,FB(1,1)
          CALL REPLCE(XR2,XR2D)
C GROUND ABSORPTION
      72  DO 73 KF=1,NF
          FG(KF)=1.
      73  CONTINUE
C         ICODE=13
C         WRITE(IOUT,1000)ICODE,XR1,XR2,XR2D
          IF(DELPU(1).GT.-0.2)GO TO 78
          IF(KGA.EQ.0)GO TO 78
          DO 77 IGRA=1,KGA
          LOC=KGCODE(IGRA)
          CALL REPLCE(TA1(1,1,IGRA),XG1)
          CALL REPLCE(TA1(1,2,IGRA),XG2)
          BG=BGT(IGRA)
          IKIND=IKIN(IGRA)
C         ICODE=14
C         WRITE(IOUT,1001)ICODE,LOC,XG1,XG2
          IF(LOC.EQ.3)GO TO 74
          CALL ENDPT(XR1,XR2,XRC,XG1,XG2,XK,KTRIG,IERR)
          IF(IERR.EQ.4) RETURN
          IF(KTRIG.EQ.0)GO TO 77
          GO TO 75
      74  CALL REPLCE(XR2,XK)
      75  CALL NR1(XR1,XK,XRC,XNPT,DIST,XN1,DN1)
          HDIFF=HEIGHT(XN1,XRC,XG1,XG2)
          IF(HDIFF.GT.HGA(IKIND))GO TO 77
          CALL SECTN(XR1,XK,XRC,XG1,XG2,XG3,XG4)
          DL=1.57/(1./BG+1./AMAG(XG3,XG4))
          DO 76 IK=1,NF
          PP=IK
          IF(IK.EQ.1)PP=5.
          IF(IKIND.EQ.1)A=(.0016*PP-0.0028)*DL
          IF(IKIND.EQ.2)A=2.**(PP/3.)/1310.*DL
          IF(A.GT.2.)A=2.
          FG(IK)=FG(IK)/10.**A
          IF(FG(IK).LT.1.E-2)FG(IK)=1.E-2
      76  CONTINUE
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
      CALL REPLCE(XK, XR2)
C     ICODE=15
C     WRITE(IOUT,1   )ICODE,FG(1),FG(9)
   77 CONTINUE
   78 CALL REPLCE(XR2,XR2G)
C PRELIMINARY SELECTION OF REFLECTORS
      NREF=0
      IF(NB.EQ.0)GO TO 91
      NRFDF=0
      KBAR=0
      DO 85 IBAR=1,NB
      KAR=IBLAST(IBAR)
      XRB1(1)=BX(IBAR,1)
      XRB1(2)=BY(IBAR,1)
      XRB1(3)=BZ(IBAR,1)
      NLIM=VBSM1(IBAR)+1
      DO 85 ISEG=2,NLIM
      XRB2(1)=BX(IBAR,ISEG)
      XRB2(2)=BY(IBAR,ISEG)
      XRB2(3)=BZ(IBAR,ISEG)
      KBAR=KBAR+1
C     ICODE=16
C     WRITE(IOUT,1001)ICODE,KBAR,XR1,XR2,XRB1,XRB2
      CALL IMAGE(XRB1,XRB2,XRC,XRCI)
      CALL NRPT(XR1,XR2,XRCI,XNPTI,DISTI)
C     ICODE=17
C     WRITE(IOUT,1  )ICODE,XRCI,XNPTI
      ANGIMG=ANGLE(XRB1,XRB2,XRCI)
      FCTR=(DIST*ANGIMG)/DISTI/ANG/FB(1,1)
      IF(FCTR LT.0.1)GO TO 80
      NRFDF=NRFDF+1
      KRDNUM(NRFDF)=KBAR
      CALL REPLCE(XRB1,RB1(1,1,NRFDF))
      CALL REPLCE(XRB2,RB1(1,2,NRFDF))
C     ICODE=18
C     WRITE(IOUT,1001)ICODE,NRFDF,XRB1,XRB2
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
      IF(KAR.NE.IR)GO TO 80
      CALL DEGEN(XR1,XR2,XRCI,XRB1,XRB2,LOC)
      IF (LOC.EQ 5) CALL BLOCN(XR1,XR2,XRCI,XRB1,XRB2,XK,LOC)
   79 IF(LOC.EQ.0)GO TO 80
      NREF=NREF+1
      KRNUMB(NREF)=KBAR
      CALL REPLCE(XRB1,R1(1,1,NREF))
      CALL REPLCE(XRB2,R1(1,2,NREF))
C     ICODE=19
C     WRITE(IOUT,1001)ICODE,NREF,XRB1,XRB2
    8 CALL REPLCE(XRB2,XRB1)
   85 CONTINUE
C BEGIN REFLECTOR PROBLEM
   91 IDXK=0
      IF(NREF EQ.0)GO TO 180
      DO 175 KREF=1,NREF
      KBAR1=KRNUMB(KREF)
      CALL REPLCE(R1(1,1,KREF),XRB1)
      CALL REPLCE(R1(1,2,KREF),XRB2)
C     ICODE=20
C     WRITE(IOUT,1001)ICODE,KBAR1,XRB1,XRB2,XR1,XR2
      CALL IMAGE(XRB1,XRB2,XRC,XRCI)
      CALL ENDPT(XR1,XR2,XRCI,XRB1,XRB2,XK,KTRIG,IERR)
      IF(IERR EQ.4) RETURN
C     ICODE=21
C     WRITE(IOUT,1001)ICODE,KTRIG,XRCI,XK
      IF(KTRIG.EQ.0)GO TO 175
      CALL NRPT(XR1,XR2,XRCI,XNPTI,DISTI)
      CALL NR1(XR1,XK,XRCI,XNPTI,DISTI,XN1I,DN1I)
C     ICODE=22
C     WRITE(IOUT,1001)ICODE,XNPTI,XN1I
      XN1I(3)=XN1I(3)+ZS(2)
      HDIFF=HEIGHT(XN1I,XRCI,XRB1,XRB2)
      IF(HDIFF GT.-2.0)GO TO 175
      CALL REPLCE(XK,XR2)
      CALL SECTN(XR1,XR2,XRCI,XRB1,XRB2,XRB3,XRB4)
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
C     ICODE=23
C     WRITE(IOUT,1000)ICODE,XR1,XR2,XRB3,XRB4
      MDIFF=
      DO 95 IQ=1,NQ
      DELP1(IQ)=-0.2
      DELP2(IQ)=-0.2
   95 CONTINUE
C DIFFRACTION BEFORE REFLECTION
      IF(NRFDF EQ.0)GO TO 115
      DO 11  KRFDF=1,NRFDF
      KBAR2=KRDNUM(KRFDF)
      CALL REPLCE(RB1(1,1,KRFDF),XDB1)
      CALL REPLCE(RB1(1,2,KRFDF),XDB2)
C     ICODE=24
C     WRITE(IOUT,1001)ICODE,KBAR2,XDB1,XDB2
      IF(KBAR2.EQ.KBAR1)GO TO 110
      CALL DEGEN(XRB3,XRB4,XRCI,XDB1,XDB2,LOC)
      IF (LOC.EQ 5) CALL BLOCN(XRB3,XRB4,XRCI,XDB1,XDB2,XK,LOC)
   96 IF(LOC.NE.0)GO TO 110
      CALL ENDPT(XR1,XR2,XRCI,XDB1,XDB2,XK,KTRIG,IERR)
      IF(IERR EQ 4) RETURN
C     ICODE=25
C     WRITE(IOUT,1001)ICODE,KTRIG,XK
      IF(KTRIG.EQ.0)GO TO 110
      CALL NR1(XR1,XK,XRCI,XNPTI,DISTI,XN1I,DN1I)
C     ICODE=26
C     WRITE(IOUT,1000)ICODE,XN1I
      ZN10=XN1I(3)
      XN1I(3)=ZN10+ZS(1)
      HDIFF=HEIGHT(XN1I,XRCI,XDB1,XDB2)
      IF(HDIFF.GT.20.0)GO TO 110
      CALL SECTN(XR1,XK,XRCI,XDB1,XDB2,XDB3,XDB4)
C     ICODE=27
C     WRITE(IOUT,1000)ICODE,XDB3,XDB4
      CALL NRPT(XDB3,XDB4,XRCI,XNPTJ,DISTJ)
      CALL NR1(XDB3,XDB4,XRCI,XNPTJ,DISTJ,XN2,DN2)
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
C        ICODE=127
C        WRITE(IOUT,1000)ICODE,XNPTJ,XN2,DISTJ,DN2
         HDIFF=HEIGHT(XN2,XRCI,XRB1,XRB2)
C        ICODE=227
C        WRITE(IOUT,1002)ICODE,HDIFF
         IF(HDIFF.GT.-2.0)GO TO 170
         DO 105 II=1,NQ
         IQ=NQ+1-II
         DN1I=AMAG(XRCI,XN1I)
         HDIFF=HEIGHT(XN1I,XRCI,XDB1,XDB2)
         DELP=DEL(XN1I,XRCI,XDB1,XDB2,HDIFF,DN1I)
C        ICODE=327
C        WRITE(IOUT,1002)ICODE,DELP
         IF(DELP.GE.5.65.AND.IQ.EQ.2)GO TO 170
         IF(DELP.GT.DELP1(IQ))GO TO 100
         IF(IQ.EQ.1)GO TO 110
         GO TO 105
    100  MDIFF=1
         DELP1(IQ)=DELP
    105  CONTINUE
C        ICODE=28
C        WRITE(IOUT,1000)ICODE,DELP1(1),DELP1(2)
         CALL REPLCE(XK,XR2)
    110  CONTINUE
C        ICODE=29
C        WRITE(IOUT,1000)ICODE,XR2
C DIFFRACTION AFTER REFLECTION
         CALL IMAGE(XRB1,XRB2,XNPTI,XNPTJ)
         CALL IMAGE(XRB1,XRB2,XR1,XR11)
    115  CALL IMAGE(XRB1,XRB2,XR2,XR21)
C        ICODE=30
C        WRITE(IOUT,1000)ICODE,XR11,XR21,XNPTI
         IF(NRFDF.EQ.0)GO TO 145
         DO 140 KRFDF=1,NRFDF
         KBAR2=KRDNUM(KRFDF)
         CALL REPLCE(RB1(1,1,KRFDF),XDB1)
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
      CALL REPLCE(XRB1(1,2,KREF),XDB2)
C     ICODE=31
C     WRITE(IOUT,1001)ICODE,KBAR2,XDB1,XDB2
      IF(KBAR2.EQ.KBAR1)GO TO 140
      CALL INTCPT(XRB1,XRB2,XRC,XR2I,XRB4)
      CALL DEGEN(XRB3,XRB4,XRC,XDB1,XDB2,LOC)
      IF (LOC.EQ.5) CALL BLOCN(XRB3,XRB4,XRC,XDB1,XDB2,XJ,LOC)
  117 IF(LOC.EQ.0)GO TO 140
      IF(LOC.EQ.3)GO TO 120
      CALL INTCPT(XR1I,XR2I,XRC,XJ,XKI)
      XKI(3)=ZCOR(XR1I,XR2I,XKI)
      DELTA=-  5
      CALL MOVE(XKI,XKI,XR1I,DELTA,IERR)
      IF(IERR.EQ.4) RETURN
      IF(LOC.NE.1)GO TO 135
      GO TO 125
  120 CALL REPLCE(XR2I,XKI)
  125 CALL INTCPT(XR1I,XRC,XDB1,XDB2,XDB3)
C     ICODE=32
C     WRITE(IOUT,1001)ICODE,LOC,XJ,XKI,XDB3
      XDB3(3)=ZCOR(XDB1,XDB2,XDB3)
      HDIFF=HEIGHT(XR1I,XDB3,XRB1,XRB2)
      IF(HDIFF.GT.-2.0)GO TO 165
      CALL NR1(XR1I,XKI,XRC,XNPTJ,DIST1,XN1I,DN1I)
      ZN1I=XN1I(3)
      DO 130 II=1,NQ
      IQ=NQ+1-II
      XN1I(3)=ZN1I+ZS(IQ)
      DN1I=AMAG(XRC,XN1I)
      HDIFF=HEIGHT(XN1I,XRC,XDB1,XDB2)
      IF(HDIFF.GT.2.0.AND.IQ.EQ.2)GO TO 140
      DELP=DEL(XN1I,XRC,XDB1,XDB2,HDIFF,DN1I)
      IF(HDIFF.EQ.1.AND.DELP.GT.-0.2)GO TO 165
      IF(DELP.LE.DELP2(IQ))GO TO 140
      DELP2(IQ)=DELP
  130 CONTINUE
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
C       ICODE=33
C       WRITE(IOUT,1000)ICODE,DELP2(1),DELP2(2)
        IF(DELP2(2).GE.5.65)GO TO 165
   135  CALL REPLCE(XKI,XR2I)
   140  CONTINUE
   145  CALL REPLCE(XR2I,XKI)
        IDXR=IDXR+1
C       ICODE=34
C       WRITE(IOUT,1001)ICODE,IDXR,XR2I
        IF(IDXR LT 11)GO TO 150
        IERR=3
        RETURN
   150  DO 155 IQ=1,NQ
        DELR(IQ,IDXR)=DMAX1(DELP1(IQ),DELP2(IQ))
   155  CONTINUE
        DO 160 I=1,3
        XIMG(I,IDXR)=XRCI(I)
   160  CONTINUE
        GO TO 165
   165  CALL IMAGE(XRB1,XRB2,XKI,XK)
   170  CALL REPLCE(XK,XR2)
C       ICODE=35
C       WRITE(IOUT,1000)ICODE,XR2
   175  CONTINUE
C       ICODE=36
C       WRITE(IOUT,1000)ICODE,XR1,XR2
C BEGIN BARRIER FACTOR COMPUTATION
   18   NIMG=IDXR
        ANG=ANGLE(XR1,XR2,XRC)
        ADST=ANG/DIST
        IF(KPOS(XNPT,XR2,XR1).EQ.1)GO TO 190
        ANG2=ANG1-ANG
        GO TO 195
   19   ANG2=ANG1+ANG
C CONTRIBUTION FROM DIRECT RAY
   195  DO 205 IQ=1,NQ
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
      IF(NQS(MR,IQ) EQ 0)GO TO 205
      DELP=DELPO(IQ)
      DO 200 KF=1,NF
      FB(KF,IQ)=BARFAC(KF,DELP)
  200 CONTINUE
C     ICODE=37
C     WRITE(IOUT,1002)ICODE,FB(1,IQ),FB(9,IQ)
  205 CONTINUE
C CONTRIBUTION FROM REFLECTIONS
      IF(NIMG.EQ.0)GO TO 230
      DO 225 KIMG=1,NIMG
      DO 210 I=1,3
      XRCI(I)=XIMG(I,KIMG)
  210 CONTINUE
      ANGI=ANGLE(XR1,XR2,XRCI)
      CALL NRPT(XR1,XR2,XRCI,XNPTI,DISTI)
      RATIO=(ANGI/DISTI)/ADST
      DO 220 IQ=1,NQ
      IF(NQS(MR,IQ).EQ.0)GO TO 220
      DELP=DELR(IQ,KIMG)
      DO 215 KF=1,NF
      FB(KF,IQ)=FB(KF,IQ)+BARFAC(KF,DELP)*RATIO
  215 CONTINUE
  220 CONTINUE
C     ICODE=38
C     WRITE(IOUT,1002)ICODE,FB(1,1),FB(1,2),FB(9,1),FB(9,2)
  225 CONTINUE
C COMPUTE MEAN ENERGY LEVEL
  230 CALL NR1(XR1,XR2,XRC,XNPT,DIST,XN1,DN1)
      TT1=2.*ANG1
      TT2=2.*ANG2
      TE42=DABS((DSIN(TT2)+TT2-DSIN(TT1)-TT1)/4./DIST**3)
      T3=0.0
      DO 242 IF=1,NF
      IP=IF
      IF(IF.EQ.1) IP=5
```

```
C
C       A=10.**(-1 E-8*4.**IP*DN1)
C
        A=10.**(-DN1*5.4E-5*2.35**(IP-5))
        T1=0.0
        DO 240 IQ=1,NQ
        IF(NQS(MR,IQ).EQ.0) GO TO 240
        NQQ=NQS(MR,IQ)
        T2=0.0
        T4=0.0
        DO 235 I=1,NQQ
        INDEX=MR+20*(I-1)+20*5*(IF-1)+20*5*9*(IQ-1)
        T2=T2+VEXPH(MR,I,IQ)*XLREF(INDEX)
        IF(IF.EQ.1) T4=T4+VEXPH(MR,I,IQ)*XLREF(INDEX)**2
  235   CONTINUE
        T1 = T1 + FB(IF,IQ)*FG(IF)*CQ(INDEX)*T2
        IF (IF.EQ.1) T3=T3+FB(IF,IQ)**2*FG(IF)**2*CQ(INDEX)**4*T4
  240   CONTINUE
        XLE(IF)=XLE(IF)+ADST*T1*A
        IF(IF.EQ.1) CAP2=CAP2+TEM2*T3*A**2
  242   CONTINUE
C       ICODE=39
C       WRITE(IOUT,1002) ICODE,XLE(1),XLE(9),CAP2
        ANG1=DABS(ANG2)
C       ICODE=40
C       WRITE(IOUT,1000) ICODE,XR2,XR2G,XR2D,XR2)
        IF(DSQR(XR2,XR20).LT.1.0) RETURN
        DELTA=1.0
        CALL MOVE(XR2,XR1,XR10,DELTA,IERR)
        IF(IERR.EQ.4) RETURN
C       ICODE=41
C       WRITE(IOUT,1000) ICODE,XR1
        IF(DSQR(XR2,XR2G).LT.1.0) GO TO 247
        CALL REPLCE(XR2G,XR2)
        GO TO 91
  247   IF(DSQR(XR2,XR2D).LT.1.0) GO TO 25
```

SUBROUTINE GEOMRY: LISTING (Continued)

```
      CALL REPLCE (XR2D ,XR 2)
      GO TO 72
  999 FORMAT(6H CODE=I3)
 1000 FORMAT(6H CODE=I3,6F9 2/7F9 2)
 1001 FORMAT(6H CODE= I3,I4,6F9 2/6F9.2)
 1002 FORMAT(6H CODE=I3,6E13.4)
 9001 FORMAT (5X,'***   ANGLE SUBSTENDED AT RECEIVER BY ROAD SEGMENT IS
     *APPROACHING ZERO',//,11X,'INTIAL PT. OF ROAD SEGMENT ',F10.4,/,
     *11X,'END PT. OF ROAD SEGMENT',F10.4,/,11X,'RECEIVER POINT ',F10.4)
      END
```

SUBROUTINE GEOMRY: LISTING (Concluded)

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